Scheduling Elective Surgeries with Emergency Arrivals in Operating Rooms

Yao Xiao

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Goodman School of Business, Brock University

St. Catharines, Ontario

Abstract

With the growing rate of surgical expenditures, improving operating room efficiency has become one of the most important targets for health care providers. Any delays, cancellations, or no-shows, result in increased costs for a hospital. In addition, it is difficult to predict the length of surgery procedures due to the variability inherent in surgery procedure times and account for emergency cases. Effective appointment schedules, which minimize the costs of patient waiting time and surgeon idle time and overtime, play an important role in terms of improving efficiency in hospital operating rooms. This research is to develop scheduling policies for elective and emergency surgeries with the objective of reducing waiting time, idle time and overtime. Simulation-based modeling is used to formulate and evaluate different scheduling policies under different operating conditions including different distributions for surgery duration, multiple types of surgical procedures, the arrival of emergency cases and different levels of cost coefficients for idle time and overtime. These factors have not been simultaneously studied in prior studies. The modeling framework is able to account for the significant uncertainty and complexity present in this problem setting. Historical surgery procedure data over a two-year period from the Canadian Institute for Health Information (CIHI) database is used to provide empirical support for the input parameters of the model and validate the efficiency of the different scheduling policies.

Key Words: surgery scheduling; emergency arrivals; simulation

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1. Introduction

1.1 Motivation

Surgical service procedures in hospital operating rooms (ORs) are one of the most important activities in a hospital. ORs provide a major source of revenues for a hospital. They have been estimated to account for more than 40% of hospital's total revenues (Erdogan and Denton, 2011). However, ORs also account for approximately 40% of hospital resource costs, including expenditures on staff members (e.g., surgeons, anesthetists, nurses) and facilities (e.g., operating rooms, intensive care beds, recovery rooms) (Macario et al., 1995). Furthermore, aggregate surgery expenditures are expected to increase from $572 billion in 2005 (4.6% of US GDP) to $912 billion in the year 2025 (7.3% of US GDP) which is approximately a 60% increase (Muñoz et al., 2010). In this context, process improvements in OR efficiency that involve expenditures, patient flow, timely treatment, and utilization of available resources, are very important for hospitals.

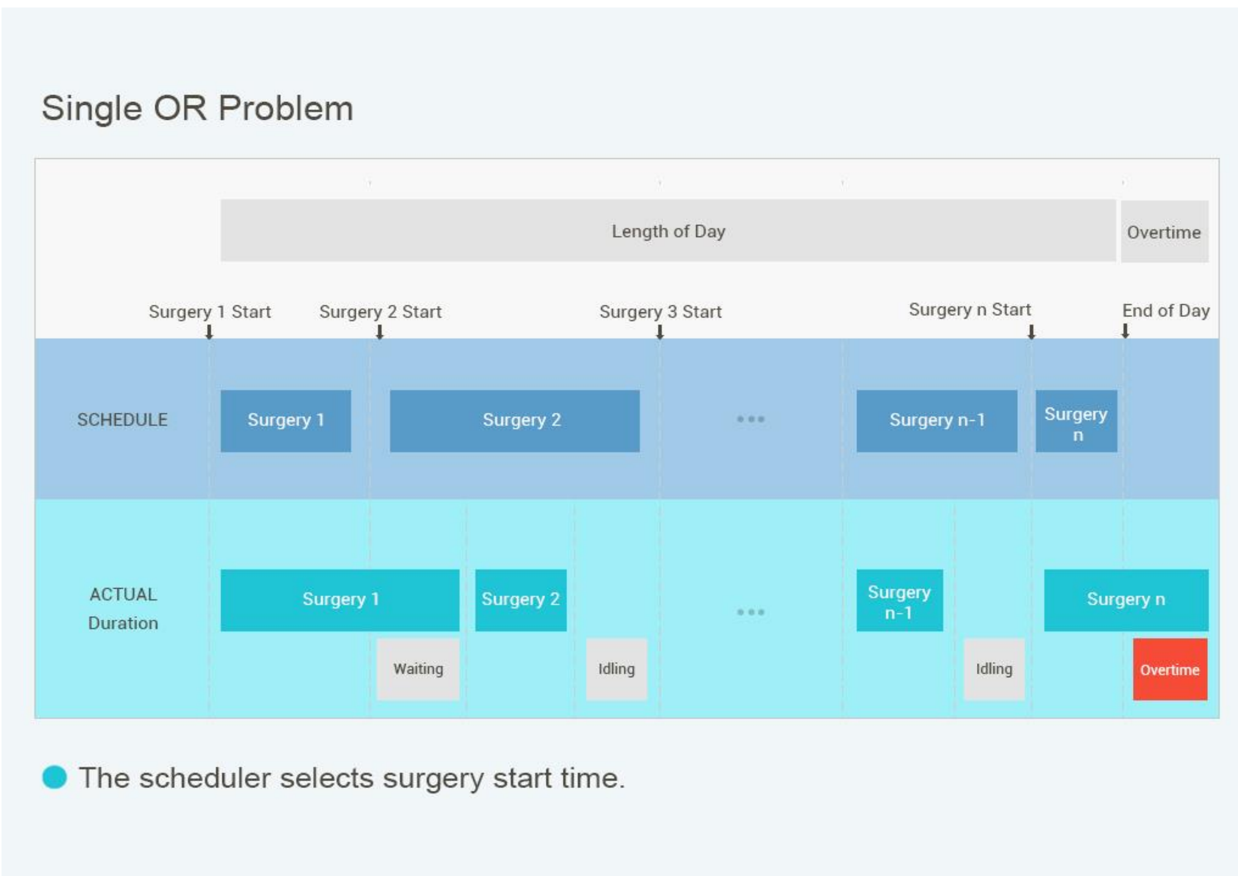
Appointment systems have been shown to be effective in increasing efficiency by decreasing patient waiting time, surgeon idle time and surgery overtime (Cayirli et al. 2003). An ineffective schedule is one of the main reasons for inefficiency in ORs (Weinbroum et al. 2003). The main goal of an OR manager is to ensure optimal usage of surgeons and surgical teams, punctual surgery start times, and minimal patient waiting time without increasing costs. Inefficient and inaccurate planning and scheduling of OR time may cause either delays of surgery or cancellations, which are expensive to the patient and the hospital (Gordon et al., 1988). Poor scheduling also has an impact on other processes in a hospital, such as nurse schedules and inpatient beds planning (Cardoen et al., 2009). In this thesis, a simulation approach is used to develop scheduling policies for elective and emergency surgery procedures in hospital ORs.

1.2 Research Context

Scheduling surgery cases is a complex task. First, the surgery durations are uncertain. The time required for a completed surgery such as patient setup and anesthesia time, surgery act execution procedure time, and operating room cleaning and setup time, is highly variable. Studies have shown that factors such as severity of illness, personnel, and procedure type might influence the accuracy of surgery duration estimations (Kayis et al., 2012). The uncertainty also has an impact on a variety of expensive resources including operating rooms (ORs), the post anesthesia care unit (PACU), intensive care unit (ICU), and hospital beds.

Figure 1

Basic Problem in Single OR



A basic problem in single OR is showed in Figure 1 (Erdogan and Denton, 2011). The scheduler will determine the surgery start time for each case in surgery schedule. If the surgery duration is longer than expected, the surgeons may have to work overtime. It also increases the waiting time for next patient and affects the sequence of surgeries. By contrast, if the surgery duration is shorter than expected, the idle time of surgeons may be increased. Inaccuracy in predicting surgery duration may have the effect of decreasing the utilization of ORs. The surgery scheduling problem involves the selection of surgeries to be performed, the allocation of resource time to OR, and the sequencing of the procedures within the allocated time (May et al., 2010). However, the significant variability in surgery duration makes this a very difficult problem to solve.

Second, the schedule must also accommodate emergency cases. A hospital generally admits two types of patients: elective patients, who are scheduled in advance and emergency patients, who arrive randomly (Lamiri et al., 2008). These emergency cases can only be delayed for a limited time that complicates the development of a schedule. Being able to meet the demand for elective surgeries is not enough for effective surgery scheduling. Balancing the sequence of emergency cases and elective surgeries and determining the allocation of OR rooms and surgeons are important for an OR manager.

Third, an effective surgery schedule needs to take into account other variability such as delays, cancellations or no-shows. Surgery delay refers to the interval length between the start time based on the timetable and actual surgery start time. Delays in surgery might come from the uncertain durations and the arrival of emergency cases. Surgery cancellation indicates calling off the surgery arrangement. Patient no-shows mean patients do not keep surgery appointment. Any delays, cancellations, or no-shows result in a negative effect on performance. They not only increase the idle time of surgeons but also occupy unused resources. Surgery schedulers want to minimize staff members idle time and keep the OR utilization high.

The current literature on OR scheduling categorizes the scheduling process in three stages (Santibáñez et al., 2007; Beliën and Demeulemeester, 2007; Testi et al., 2007). The first stage refers to *Case Mix Planning*, or Session Planning (Testi et al., 2007). It determines how much OR time will be assigned to surgeons or surgical specialties. These studies used linear programming models (e.g. Hughes and Soliman, 1985; Blake and Carter, 2002) and integer programming (Blake et al., 2002) to determine the optimal OR time allocation.

The second stage involves developing the *Master Surgery Schedule* (MSS), a cyclic timetable that includes the number and type of ORs available, the hours the rooms will be open, and the surgeons who are to be given priority for the OR time (Blaker et al., 2002). There are two objectives of the MSS: (1) Assigning the total hours of operating time (i.e., block time) to each surgeon or surgical group such that this time is as near the target assigned amount of hours as possible (2) Constructing a schedule that does not vary widely from the previous schedule. The MSS can be used repetitively for a period of time. However, a new MSS needs to be created when conditions change such as the opening hours for ORs, different seasonal demand, the number of ORs that can be used, or working hours for surgeons. It is a time-consuming and complex task for the OR manager to recreate schedules repeatedly. The variability inherent in surgery procedure times complicates the development of this schedule (van Oostrum et al., 2008). In addition, a block schedule occupies an OR for a whole day, so it is hard to arrange an accurate start time for subsequent surgeries during the day. Studies have primarily used integer programming to develop an optimal MMS (Blake and Donald, 2002; Beliën and Demeulemeester, 2005).

The literature has primarily studied three types of scheduling systems used in MSS: *open-scheduling*, *block-scheduling*, and *modified-block scheduling*. Open-scheduling uses the first come first served (FCFS) policy. An empty schedule (no time blocks) is filled up with surgery cases.

The aim of open-scheduling is to accommodate all patients. The surgeons can submit cases until the day of surgery. Therefore the advantage of open-scheduling is it favors surgeons who can schedule far in advance, such as ophthalmology and plastic surgery. However, it is difficult to accommodate general surgeons who cannot plan so far ahead, such as cardiac surgery and orthopedics (Patterson, 1996).

Block-scheduling is more predictable. It allows surgeons to be assigned surgery times in a relatively fixed schedule. In this system, a master surgery schedule will be created in advance which allocates time blocks to surgeons. The surgeons then allocate their cases to their reserved time blocks. Surgeons normally have to fit all procedures (including emergency cases) within an assigned block of time and have their own preferences in terms of the surgery days and times (Gupta and Denton, 2008).

Besides open and block-scheduling, a third scheduling system is modified block-scheduling. It combines the characteristics of both open and block scheduling (Patterson, 1996). Modified block-scheduling can be performed in two ways. The first way is to assign blocks to surgeons, with some blocks reserved or left open to be released to other surgeons. The second way is to assign blocks of time to surgeons with stipulation that any unused block time be released at some time prior to the surgery data. Modified block-scheduling policy balances needs of surgeries that can be booked in advance (e.g., ophthalmology and plastic surgery) with those surgeries that cannot be scheduled far in advance (e.g., cardiac surgery and orthopedics) (Patterson, 1996). It also increases OR utilization by releasing unused time blocks but still provides surgeons with a predictable schedule which they can book time.

The third stage refers to *Case Scheduling*, or Elective Case Scheduling (ECS) (Testi et al., 2007). It is a process of assigning specific cases to particular ORs, determining the sequence of surgery cases, start and end times of the cases, and availability of specialized equipment (Weiss, 1990; Ozkarahan, 2000; Denton et al., 2007). The focus of this paper is on the third stage. The goal is to increase OR utilization and reduce waiting time, idle time and overtime.

Prior studies have primarily used analytical methods such as integer programming (Blake et al., 2002; van Essen et al., 2012a), mixed integer programming (Jebali et al., 2006), linear programming (Dexter et al., 1999d; Kuo et al., 2003; Pham and Klinkert, 2008), stochastic dynamic programming (Gerchak et al., 1996), and goal programming (Ozkarahan, 2000; Ogulata and Erol, 2003) to solve the OR scheduling problem.

Simulation has been used to a lesser extent to study surgery scheduling policies for elective surgery cases (Dexter et al., 1999c; Everett, 2002; Tanzania and Testi, 2010; M’Hallah and Al-Roomi, 2014, Lebowitz, 2003). Simulation also has been used to explore different surgery scheduling policies such as Longest Processing Time first (LPT), Shortest Processing Time first (SPT) rules (Testi et al., 2007; Sciomachen et al., 2005), First Come First Served (FCFS), Longest Time first followed by Shortest first (LTSC, also known as top-down bottom-up scheduling) (Harper, 2002). Other policy that has been studied is Longest Waiting Time first (LWT) (Harper, 2002; Testi et al., 2007). In this case, patients are scheduled based on how long they have been waiting for their procedure to be scheduled.

One of the most difficult tasks in scheduling surgeries is to accommodate elective surgery under a variety of operating conditions. Operating conditions that have been studied previously include surgery durations (Dexter et al., 1999d; Strum et al., 2000; Broka et al., 2003; Spangler et al., 2004), emergencies (Wullink et al., 2007), and cancellations or no shows (Kim and Horowitz, 2002; Basson et al., 2006).

1.3 Research Goals and Contributions

The surgery scheduling problem involves the selection of surgeries to be performed, the allocation of resource time to ORs, and the sequencing of procedures within the allocated time (May et al., 2010). Variable surgery durations, multiple surgical types and emergency cases make this problem more complex for OR managers. Effective appointment schedules, which reduce the cost of patient waiting time and facility idle time and overtime under these conditions, play an important role in terms of improving efficiency in hospital operating rooms.

Prior literature has mostly used analytical methods to address the surgery scheduling problem. Analytical methods were used to find optimal surgery schedule and optimize the performance measure. Typically, they optimize some combination of patient waiting time, surgeon idle time, and overtime. In addition, they focus on maximizing OR utilization and minimizing expenditure. The benefit of simulation over analytical methods is its ability to model complex systems and to take into account uncertainties. Researchers can easily modify the simulation model to test different scenarios, so they can assess how specific problems and assumptions affect the analysis. Some studies used simulation to consider the arrival of emergency cases, sequence of elective surgery, and reduction of patient waiting time on the waiting list. It also has been used to evaluate different sequencing policies. However, simulation has not been used to develop surgery scheduling policies for elective surgery cases while simultaneously incorporating the significant uncertainty generated by the arrival of emergency procedures in ORs. The key advantages of simulation for this research are that (1) it can incorporate uncertainty in surgery duration and emergency cases explicitly into the analysis, (2) it can account for the complexity of surgery systems, and (3) it can test different scenarios without changing anything in the real surgery system. Thus, simulation modeling is an effective approach to be used in this study.

In this thesis, simulation-based modeling is used to develop scheduling policies for elective and emergency procedures based on open and block-scheduling systems. Open-scheduling systems use the first come first served (FCFS) policy while block-scheduling systems assign surgery times to surgeons in a relatively fixed schedule in advance. Our scheduling problem involves determining surgery start times and the sequence of surgeries with the objective of reducing the expected total cost of patient waiting time, OR idle time and overtime. The performance of these policies is evaluated under different operating conditions including different distributions of surgery duration, multiple types of surgical procedure, the arrival of emergency cases and different levels of cost coefficient for idle time and overtime. The goal is to develop scheduling policies that are robust over a wide range of environmental conditions.

In order to empirically validate the performance of different policies, this research uses real data on surgery durations from the Canadian Institute for Health Information (CIHI). Historical surgery duration data over a two-year period from CIHI database is used to provide empirical support for the input parameters of the model. The probability distributions derived from the data are used to build a realistic model of the system. The simulation software ARENA 10.0 is used to construct a simulation model of the system and evaluate different surgery scheduling policies under different operating conditions.

This research contributes to the literature and practice in several ways. For literature, it identifies scheduling policies that are unique in terms of capturing the significant uncertainty and complexity found in this problem setting. In addition, the data obtained may be valuable in providing further empirical support for the parameters of this problem providing new insights into how surgery systems operate. For practice, this study hopes to provide insights to hospitals on the type of scheduling rules, in terms of interval length and sequencing, that might be used to improve overall performance.

The rest of this study will be organized as follows. Section 2 reviews the literature in surgery scheduling. Section 3 discusses the methodology and problem formulation. Section 4 provides results and analysis of this research. Section 5 summarizes the conclusions of this study. Section 6 emphasizes the implication for literature and practice and outlines the future research guidance.

2. Literature Review

Surgery scheduling has been studied extensively in the literature. The surgery scheduling problem involves the selection of surgeries to be performed, the allocation of resource time to OR, and the sequencing of the procedures within the allocated time (May et al., 2010). The uncertainty of emergency case arrivals, variability inherent in surgery procedure times, and no shows or cancellations for surgery make planning in an OR setting very complex. A well-designed surgery schedule is crucial for improving operational efficiency since it can have a significant impact on (1) minimizing the cost of surgeon idle time and overtime, (2) reducing waiting times for unscheduled patient without increasing the patient waiting time in elective surgeries and (3) reducing the negative impact on OR utilization. In this section, this paper reviews the literature in two main scheduling methods in surgery scheduling (i.e., open and block scheduling), variability (i.e., uncertain duration, emergency cases, cancellations and no-shows) and different methodologies in surgery scheduling (i.e., analytical methods and simulation).

2.1 Open and Block-scheduling

The literature has primarily studied three types of scheduling system: open-scheduling, block-scheduling, and modified-block scheduling. For open-scheduling, Fei et al. (2009) assigned surgery cases to ORs by adopting an open-scheduling policy. They constructed a mathematical model to analyze the surgery scheduling problem and aimed to maximize OR utilization and minimize the overtime cost. Fei et al. (2010) also used an open-scheduling policy to develop a weekly surgery schedule in order to improve the performance in ORs. In their paper, they assumed that surgeons could allocate their surgery cases into time blocks reserved with the block scheduling strategy until Thursday evening. Then using open scheduling strategy, the final surgery schedule of the coming week would be decided by an OR manager on Friday. Their goal was to optimize the utilization of ORs, reduce the overtime cost, and the unexpected idle time between surgery cases.

Block-scheduling is a commonly used strategy in surgery scheduling (Guerriero and Guido, 2003). Dexter et al. (1999c) pointed out that the key to maximizing utilization of ORs is to determine the number of blocks allocated to surgeons and the day to schedule the surgery. Dexter et al. (2000) proposed “Overflow” block time which is OR time for a surgical group’s surgeries that could not be finished in regular block time assigned to each surgeon in surgical groups. They suggested assigning regular block time to each surgeon and allocating “Overflow” block time to the whole surgical group (i.e. all surgeons who operate at surgical suite). Even though the overflow block time increases OR utilization, OR manager need to concern staffing costs and surgeons and patients preference on surgery dates and times. Dexter et al. (2003) calculated the ORs utilization rate to determine whether the block time allocation was reasonable for low caseload surgeons. The results indicated that OR utilization alone is not an accurate metric for the allocation of OR time. Planners should also account for OR efficiency in OR time allocation. Wachtel and Dexter (2008) argued that other than past utilization of OR block time, additional OR time should be assigned to those subspecialties that have high margin per OR hour. This could be calculated from the total revenues and total variable costs for all surgery cases combined, and from the total hours of OR time for all surgery cases combined. The additional OR time also could be assigned based on other criteria such as the potential for development (e.g., data development analysis) and the requirement for constrained assets (e.g., less require for a limited resource such as intensive care units bed).

Besides open and block-scheduling, a third advanced scheduling method is modified block-scheduling. It combines the characteristics of first come first served and block formats (Patterson, 1996). Modified block-scheduling can be performed in two ways. The first way is to assign blocks to major surgeons, with some blocks are released to other users. The second way is to release some available time blocks before surgery (e.g.72 hours) to other surgeons. Dexter (2000) adopted the modified block-scheduling to find a better allocation of surgery cases to reduce overtime labor cost. He developed an approach, which estimated the staffs overtime cost, for determining the best time to transfer the last case of the day to another available OR in terms of reduced overtime cost.

2.2 Analytical Methods

Most studies used different kinds of mathematical modeling techniques to develop surgery schedules. The objective is to maximize operating room utilization or minimizing operating room team expenditure. OR utilization can be calculated by adopting various methods. Surgery schedulers are responsible for scheduling enough surgeries each week within their block time to meet the utilization requirement. Surgeons who occupy block schedules need to maintain a certain level of usage during their time blocks. Otherwise, they waste OR resources which originally can be used to perform more surgeries and increase the cost of surgeon idle time. Therefore, utilization can be calculated regarding the availability of OR times and its usage level.

Blake et al. (2002) proposed an integer programming model to produce a master surgery schedule that does not vary widely from the previous schedule. As a result, the number of OR times assigned to surgeons is as close to the target number of OR hours as possible. van Essen et al. (2012a) used integer programming to determine the best adjusted rule in rescheduling surgeries on the execution day. The adjustments they used were (1) shifting surgeries (i.e. switching the time slots for two surgeries) between two surgeries and (2) scheduling breaks between two surgeries. After adopting these adjustments, the results showed that it decreased the amount of canceled surgeries and increased the satisfaction of patients, but also increased the workload to compensate them. Jebali et al. (2006) used mixed integer programming to present a two-step approach for surgery scheduling problem. The first step was to allocate surgeries to specific ORs. The second step was to sequence the assigned surgeries in order to improve the utilization by considering the resource restrictions. Their sequencing policy was more focusing on resource usage (such as staff, equipment, recovery bed availability) than surgery scheduling (such as adjusts the interval between surgery cases).

Goal programming has been used to develop surgery schedules. Ozkarahan (2000) developed a goal programming model to construct a surgery schedule in order to reduce surgeon idle time and overtime and increase the satisfaction of surgeons, patients, and staff. Their model involved categorizing the requests for a specific day based on the block restrictions, OR utilization, surgeon preferences, and intensive care capabilities. The goal of this study was to build a model that could consider conflicting objectives in the OR environment and accommodate different needs. The results proved the goal programming model was better than the hospital's current scheduling policy in terms of utilization and overtime. Ogulata and Erol (2003) used goal programming to construct a set of hierarchical multiple criteria mathematical programming models to develop surgery schedules for ORs. The overall problem could be separated into three steps: (1) selecting patients, (2) allocating surgeries to surgeons and (3) determining the surgery execution dates and specific ORs. They aimed to maximize the utilization of ORs, balance the allocation of surgeons to ORs, and reduce patient waiting time.

Linear programming has been utilized in research studies to improve surgery scheduling. Kuo et al. (2003) constructed a linear programming model to optimize OR time allocation among a group of surgeons while considering financial returns. Their results showed that mathematical modeling could be used to increase revenue and reduce cost. Pham and Klinkert (2008) formulated a mixed integer linear programming model for scheduling elective and add-on surgeries (e.g., emergency cases). Their paper pointed out the significance of associating surgical stages (i.e., preoperative stages, perioperative stages and postoperative stages) and organizing different resources during those steps. Dexter et al. (1999d) used a linear programming model to estimate the surgery durations and determine whether the use of sample means of historical data was a good method to predict surgery completion time. They found that the mean of the time to finish a series of surgeries would equal the sum of mean times to finish each surgery. However, the use of sample means would not minimize the labor costs related to predicted errors in completion time.

Analytical methods have been used to consider different uncertainties in surgery scheduling problem. One significant challenge for surgery scheduling is the uncertainty of surgery procedure durations. Inaccuracy in predicting surgery duration may have the effect of decreasing the utilization of ORs. Even though perfect estimation of surgery durations is impractical, developing a better estimation method may have a positive influence on costs related to the utilization of ORs (Olsen, 2015).

Some studies have used the means or median from historical data to estimate surgery durations. Dexter et al. (1999d) suggested a linear model to estimate the surgery duration and determine whether the use of sample means of historical data is a good method to predict surgery completion times. They found that the mean time to finish a series of surgeries would equal the sum of mean times to finish each surgery. However, the use of sample means would not minimize the labor costs related to predicted errors in completion time. Broka et al. (2003) proposed a strategy to manage ORs based on the median duration times from previous case times individualized by the surgeon. Their results indicated that this measurement related to the daily limit could reduce overruns and delays before the surgery. The log normal distribution has been widely chosen for generating surgery case duration (Dexter et al., 1999c; Spangler et al., 2004). It is a popular statistical distribution for modeling the variability inherent in surgery procedure times. Spangler et al. (2004) found that adopting a second-order regression model to calculate the location parameter of the lognormal distribution for surgery duration provides a better estimation than sample means from historical data. Strum et al. (2000) compared lognormal and normal distributions of surgery times. Their results indicated that surgery times fit the lognormal distribution significantly better than the normal distribution model.

The problem of variability in surgery duration has also been studied by considering the sequence of surgery cases as a factor. Denton et al. (2007) studied the impact of sequencing surgeries and scheduling start times simultaneously. They used a stochastic optimization model and practical heuristics to investigate the impact of uncertainty in surgery durations. Their results showed that a simple sequencing rule based on surgery duration variance could reduce OR team's waiting time, idling time and overtime costs. Weiss (1990) focused on sequencing surgeries and estimation of optimal surgery start times. They found that the estimated surgery start times could be found based on a single critical number that was from the probability distribution of surgery duration.

Another complex problem in surgery scheduling is the uncertainty in the number of patients to be scheduled on a specific day. Surgery at hospitals can be classified as elective and emergency cases (Cardoen et al., 2010). Elective surgeries are scheduled well in advance (e.g., months) to be performed on a future date while emergency surgeries occur unexpectedly. Accommodating emergency surgeries is a complicated task. These emergency cases normally would be inserted into the existing schedule, either by using intentionally reserved or otherwise available OR spots in the schedule, or by creating room by canceling elective cases (Erdogan and Denton, 2011).

van Essen et al. (2012b) used heuristics solution methods to investigate the effect of scheduling emergency surgery cases in one of the elective ORs. The emergency case could be operated on as soon as the elective surgery finished. The arrival of emergency surgery cases followed a Poisson process and surgical times of elective cases followed a log-normal distribution. Then they used simulation to evaluate the scheduling process performance that reduces the waiting time of emergency cases. Pham and Klinkert (2008) adopted mixed integer linear programming to investigate how the arriving emergency surgeries should be incorporated into the elective surgery schedule. They pointed out the importance of the connection of different surgical stages (i.e., preoperative stages, perioperative stages and postoperative stages) and coordination of multiple resources during those stages. Lamiri et al. (2008) determined the number of elective surgeries to be allocated to ORs with emergency cases. They proposed a stochastic mathematical programming model and aimed to reduce the cost of OR utilization. They found that it is able to produce a near-optimal schedule with 12 ORs and about 210 elective patients. Gerchak et al. (1996) focused on the advanced scheduling of elective surgery when the usage of ORs for both emergency cases and elective cases is uncertain. They provided a stochastic dynamic programming model to determine the number of additional requests for elective surgery that can be allocated at the beginning of each day. Dexter et al. (1999) determined the optimal sequencing of emergency surgeries to enhance patient safety and satisfaction. The sequencing is based on three scheduling objectives: 1) minimizing the patient average waiting time, 2) scheduling the surgeries that are submitted to ORs, 3) sequencing the cases based on medical urgency.

Delays, cancellations or no-shows of elective surgeries cause further uncertainty in the surgery scheduling process. They not only increase idle time of the surgeons but also increase costs of the whole procedure (e.g., expenditures for labor and facilities maintenance). The reasons for delays include inaccurate surgery timetables and arrivals of emergency cases. The main reasons for cancellations are the failure to get consent and related medical illness or re-evaluation, and inability to follow preoperative instructions (Hand et al., 1990). The reasons for no-shows are transportation, scheduling arrangement, forgotten appointment and children care problem (Campbell et al., 2000).

Basson et al. (2006) focus on the effect of surgery cancellations on OR utilization and found that patient no-shows could be predicted from patient non-compliance with clinic visit and clinical process. By setting advanced scheduling of elective surgeries, Kim and Horowitz (2002) determined whether employing a quota system could enhance the performance in serving patients. Their results showed that the combination of the quota system and flexible bed allocation scheme helps to reduce the number of canceled surgeries without increasing waiting times of other patients.

2.3 Simulation

Compared to analytical methods, simulation is able to model complex systems and to consider uncertainties and variability in surgery scheduling. It has the ability to test multiple scenarios. A survey paper by Jun et al. (1999) discusses the main practical uses of discrete event simulation in health care clinics in the past 20 years. They suggest that simulation can be used in hospital settings to forecast the effect of changes in patient flow, investigate resource needs, or study the complex relationships among the different model variables. It can also be used to evaluate the efficiency of existing delivery systems and ask 'what if?' questions without changing anything in the real system.

Several studies have used simulation to schedule surgery cases in ORs. M’Hallah and Al-Roomi (2014) simulated assigning surgery cases to ORs to improve the under and over utilization. They investigated three scheduling strategies: (1) moving a surgery case from a busy OR to an available OR, (2) adopting a single queue for all ORs and (3) choosing an alternative OR set up where surgeries are categorized by type. Their results indicated that, given the variability in OR durations, using a single queue for all surgery cases is better for all ORs. They also found that mixing types of surgery cases is better than separating them by type only if the hospital reduces the number of minor cases allocated to the ORs. Minor cases have the shortest surgery durations and they are queued last. They generally have a higher probability of being canceled. Thus, the authors found that diverting them to an emergency department with its own independent OR improved performance. In addition, their study recommended the transfer of the last surgery case from a busy OR to an available OR. Lebowitz (2003) used simulation to develop a strategy for scheduling surgery cases in ORs by combining short and long procedures and considering their variability. The first strategy is to sequence elective surgery cases by a specific surgeon on a specific day. The second strategy is to schedule short procedures first. Their results showed that scheduling short procedures first not only could enhance on-time performance but also could reduce the overtime cost.

Simulation also has been used to consider different types of uncertainty such as surgery delays, surgery cancellations, and arriving of emergency surgery cases. Azeri-Rad et al. (2014) constructed a simulation model to represent patient pathway from admission to discharge by taking into account emergency case interruptions and bed availability. The purpose was to reduce the proportion of canceled surgery cases. Three scenarios were tested in their study. The first scenario scheduled surgeons based on patients' average length of stay in the ward. The second scenario sequenced surgery cases in order of increasing surgery duration and variation. The third scenario increased the amount of post-surgical beds. Their results indicated that those three strategies all decreased the number of surgeries cancellations. These strategies could be used individually or collectively, and therefore, enhanced performance of the whole process.

Wullink et al. (2007) used simulation to compare two capacity reserved approaches related to waiting time, staff overtime and OR utilization. The first approach focused all scheduled elective OR capacity in devoted emergency ORs. The second approach reserved capacity for emergency surgery cases in all scheduled elective ORs. Their results showed that reserving capacity in elective ORs rather than having dedicated emergency ORs leads to an improvement in waiting time, staff overtime, and OR utilization.

Some studies also adopted simulation for scheduling of patients on waiting lists for elective surgeries. Everett (2002) aimed to decrease the waiting lists by constructing a simulation model that picked up patients from waiting lists and assigned them to available time slots within a block schedule. Patients were categorized by urgency levels of surgery case (i.e., urgent, semi-urgent, routine) and types of operation (i.e., treatment procedure based on International Classification of Diseases). Their simulation models proved to be useful in improving scheduling. Dexter et al. (1999c) applied simulation to determine the optimal allocation of time blocks to surgeons and the days to perform elective surgery cases that could increase the OR utilization. According to the scheduling strategy they suggested, the number of time blocks assigned to surgeons could be determined by using the expected total hours of elective cases according to historical data, divided by the number of hours in block each day, and then rounded down to next integer. A patient might wait up to 4 weeks to be scheduled into the surgeon’s time block. Otherwise, the patient is scheduled outside the surgeon’s time block into overflow or spillover time.

Scheduling rules have been studied by using simulation in OR departments. Sciomachen et al. (2005) simulated the following rules: Longest Waiting Time first (LWT), Longest Processing Time first (LPT), and Shortest Processing Time first (SPT) rule. Their results indicated that SPT could be used to decrease the amount of surgery overtime by 54% and the total overtime by 30%

when applied to an actual hospital system. Overruns, which mean surgeries exceed their schedules' end times, can lead to significant staff overtime cost, and the LPT rule could be used to reduce overtime of each overrun but it would increase the number of overruns. Testi et al. (2007) adopted simulation to assess different sequences of surgeries within the master surgery schedule. They constructed the master surgery schedule first and then evaluated the LWT rule, the LPT rule and the SPT rule of surgeries in the waiting list. The results showed that the LPT rule increased the amount of overrun hours and operations that caused the next surgery delayed. The SPT rule, on the contrary, reduced the overruns and shifted surgeries to a later day. The LWT rule is the best to simulate what surgeons do in the real system. Harper (2002) also applied simulation to evaluate the FCFS rule, the LPT rule, the SPT rule, and the LTSC rule (longest time first followed by shortest first). Regarding system throughput and utilization, the LPT policy was found to be the optimal rule in their study. After reviewing all these papers, it can be found that under different environmental settings and objective functions, the optimal rules are different.

For this study, data from literature is used in the experiments. The OR data is summarized in Table 1. In addition, real data from CIHI is used in further experiments. Details are discussed in Section 3.

Table 1

Summary of OR Data in Literature

OR Length	Number of ORs	Arrival of Patient	Duration of Elective Surgery	Emergency Surgery	Literature
4, 7, 8 hours in each block (8 hours work day)	One surgeon at one OR suit	n/a	1, 2, 3 hours (using random number generator)	n/a	Dexter et al. (1999c)
OR regular capacity 8 hours, overtime capacity 3 hours (5 blocks one week)	3, 6, 9, 12 ORs	n/a	Randomly and uniformly generated from the interval (0.5 hours, 3 hours)	Exponentially distributed with a mean of 2 hours	Lamiri et al. (2008a)
OR regular capacity 8 hours (5 blocks one week)	2 ORs	n/a	Randomly and uniformly generated from the interval (0.5 hours, 3 hours)	Exponentially distributed with a mean of 3 hours	Lamiri et al. (2008b)
OR regular capacity 6 hours from Monday to Friday (5x6=30 hours a week), allows maximum of 30 overtime hours	6 ORs	Poisson distribution	Grouped into four classes (equal to 1.15, 1.45, 2.30 and 4.50 hours)	n/a	Testi et al. (2007)
A block 7.5 hours in working day	6 ORs	n/a	Normal distribution (0.33, 7.5 hours)	n/a	M’Hallah and Al-Roomi (2014)
6 hours a day	2 ORs	Poisson arrival with a mean arrival rate of 5 patients per day	Short, medium and long time: triangle (40, 60, 75), triangle (76, 100, 150), and triangle (151, 200, 250)	n/a	Ogulata and Erol (2003)

3. Methodology and Problem Formulation

3.1 Simulation Modeling

The research proposes simulation-based modeling for the OR scheduling problem using the software package Arena 10.0 as the implementation and evaluation tool. A detailed procedure of simulation modeling in our study is as follows:

- Data Collection: The data collected includes surgery procedure times in multiple procedure types in a single hospital. It also includes classifications for elective and emergency procedures. The data spans a two-year period and was obtained from the CIHI database.
- Input Parameters: The data was sorted and analyzed. The data was then fitted to distributions for the stochastic input parameters of the model.
- Simulation Modeling and Experiments: Simulation models were developed using Arena 10.0. Multiple models were constructed to represent different scenarios involving mean surgery durations and variability in durations. Different surgery scheduling policies were also tested. The results from the simulation experiments were analyzed by using One-way ANOVA and conclusions formed. In particular, the goal is to determine the conditions under which specific scheduling policies are best.

3.2 Problem Formulation

The goal of this surgery scheduling problem in this research is to reduce patient waiting time, surgeon idle time and OR overtime. The current model considers the operative stage and does not involve preoperative stage and postoperative stage. Various scenarios that include different surgery durations, the number of ORs, the number of surgery types, and emergency arrivals are studied to determine the best surgery scheduling rules for each set of environmental conditions.

The following notation is used:

N= Total number of patients for surgery in a block/session

SD_i= Surgery procedure duration for patient i, i=1, 2, , …, N;

t_i= Surgery start time for patient i;

WT_i=Waiting time for patient i;

IT_i= Surgeon idle time between patient i and i -1;

OT= Length of overtime

c_w= Cost coefficient for patient waiting time

c_{it}= Cost coefficient for patient idle time

c_o= Cost coefficient for surgeon overtime

d = Length of session (in this study d = 480 minutes)

Assuming that first patient waiting time $WT_1 = 0$, surgeon idle time $IT_1 = 0$, they can be described as:

$$WT_i = max\{t_{i-1} + WT_{i-1} + SD_{i-1} - t_i, 0\}, i = 2,3,4, \dots, N$$

$$IT_i = max\{t_i - (t_{i-1} + WT_{i-1} + SD_{i-1}), 0\}, i = 2,3,4, \dots, N$$

$$OT = max\{t_N + WT_N + SD_N - d, 0\}$$

Given weights regarding the cost of patient waiting time (c_w), surgeon idle time (c_{it}) and overtime (c_o), a general formulation for our problem is presented in:

$$TC = c_w E\left(\sum_{i=2}^{N} WT_i\right) + c_{it} E\left(\sum_{i=2}^{N} IT_i\right) + \ c_o E(OT)$$

$$t_i \ integer$$

3.3 Data Collection and Analysis

This study used empirical data from previous studies and data obtained from Canadian Institute for Health Information (CIHI) that was established in 1994. CIHI is an independent, not-for-profit organization that provides essential information on Canada's health system and the health of Canadian (Canadian Institute for Health Information, 2005). CIHI's data and reports are provided to help inform health policies, support the effective delivery of health services and to raise awareness among Canadians in general on current research and trends in the healthcare industry that contribute to a better health outcome (Statistics Canada, 2011).

CIHI tracks data in difference provinces with the help of information that is provided by hospitals, regional health authorities, medical practitioners and government bodies. CIHI manages a number of Canadian health data. These include the health personnel database, healthier service information, and CIHI health spending databases. Each CIHI database record is accompanied by data quality documentation that considers coverage, collection and response and general data limitation.

The data used in this study was collected anonymously from a single hospital in Canada from April 2013 to March 2015. From April 2013 to March 2014, this hospital performed 4308 surgical procedures and 113 procedure types. The procedure durations ranged from 30 minutes to 362 minutes for this year. From April 2014 to March 2015, there were 4499 procedures performed and 120 procedure types. The procedure durations for this year ranged from 30 minutes to 368 minutes.

Observations recorded consist of surgery procedure types, the date the surgery was performed, surgery start time, surgery end time, and admission category. The admission category is defined as whether the surgery performed is an elective or emergency case. The data does not contain patient, surgeon or staff identifying information.

The data set contained many different procedure types. This study selected three procedure types from the data set to represent Short (SP), Moderate (MP) and Long procedures (LP) based on their mean duration. Detailed information about the three procedure types used in this study is given in Table 2. In the two-year period, there were 798 cases Short Procedure cases, 194 cases in Moderate Procedures and 304 cases in Long Procedures. The average duration for Short Procedures is 52.9 minutes. The average duration of Moderate Procedures is 106 minutes. The average duration of Long Procedures is 153 minutes. Distributions for simulation models are determined using the historical data, with all p values are greater than 0.05 in Chi Square Test which means the modeled distribution fit the actual distribution. The histograms of the three procedure types are shown in Figures 2 to Figure 4.

Table 2

Surgeries Detailed Information from 2013 to 2015

	Short Procedures (SP)	Moderate Procedures (MP)	Long Procedures (LP)
#Observation	798	194	304
Mean Duration	52.9 minutes	106.0 minutes	153.0 minutes
Standard Deviation	20.8	39.2	53.2
Min Value	30 Minutes	47 Minutes	44 Minutes
Max Value	208 Minutes	267 Minutes	298 Minutes
Emergency Rate	4.97%	1.03%	0.00%
Distribution	30 + Expo (22.9)	47 + GAMM (29.2, 2.03)	44 + 254*BETA (1.98, 2.62)

Figure 2

Distribution of Surgery Time in Short Procedures

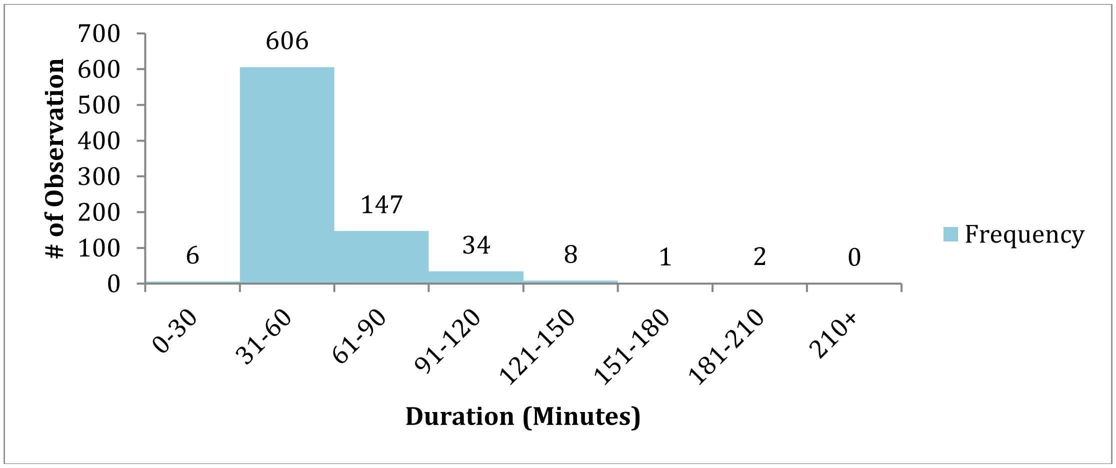


Figure 3

Distribution of Surgery Time in Moderate Procedures

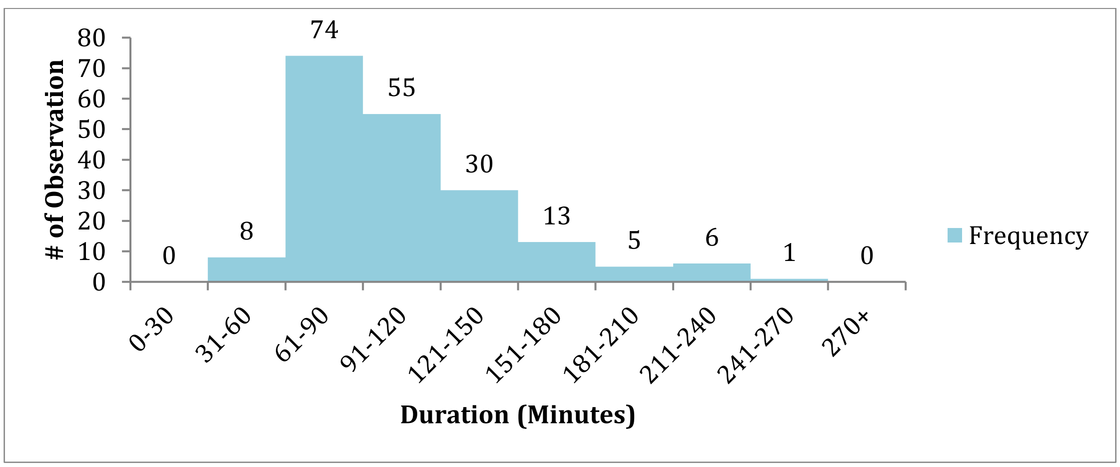
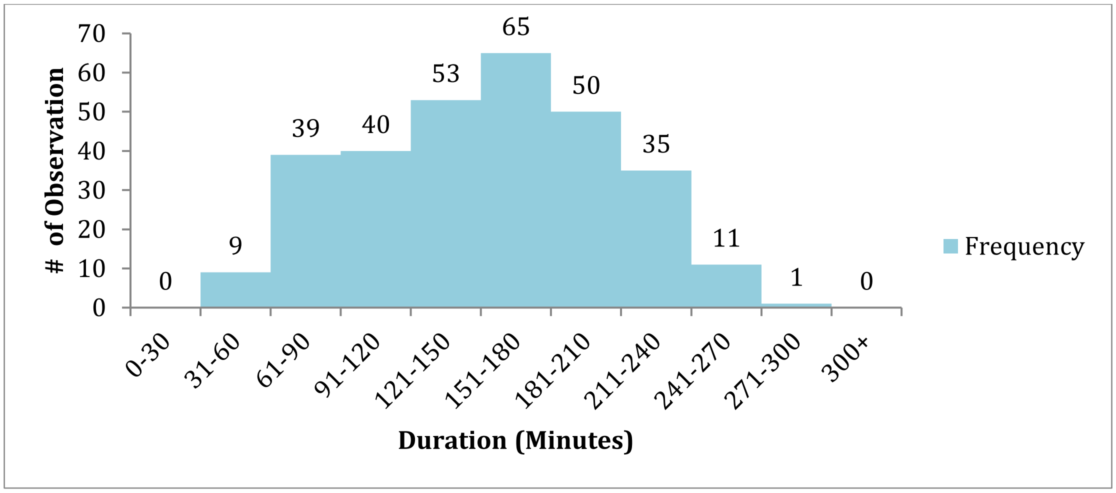


Figure 4

Distribution of Surgery Time in Long Procedures



It should be noted that this research does not focus on a case study of a single hospital. Rather, this data set is to provide support for the input parameters in this research. Thus, this data was fit to distributions for simulation model and used to produce some general conclusions in this problem setting.

3.4 Experimental Design

Three different cases are tested to study different factors, appointment rules, sequencing rules and allocation rules. Case 1 uses existing data from the previous literature. Two procedure types, Short Procedures and Long Procedures, are investigated. In Case 2, experiments use historical data on actual surgery durations obtained from CIHI. Two procedure types (i.e. Short Procedures and Long Procedures) are also used in this case. In order to learn the impact from multiple procedure types, in Case 3, an additional procedure type, Moderate, is added.

3.4.1 Factors

Four factors are investigated in this study: distributions for surgery duration, types of surgical procedures, the arrival of emergency surgeries and cost coefficients for idle time and overtime. Based on the literature (Testi et al., 2007; Lamiri et al., 2008; M'Hallah and Al-Roomi, 2014) and considering the number of surgery cases per day, six ORs are scheduled for surgeries in three cases. An eight-hour session length which is commonly found in the literature (Dexter et al., 1999c; Lamiri et al., 2008a; Lamiri et al., 2008b) is modeled for each OR.

First, different distributions for surgery duration are examined in this study. In Case 1, a log normal distribution is tested because previous research has shown that surgery procedure times fit a lognormal distribution and it is good for modeling the variability inherent in surgery procedure times (Dexter et al., 1999c; Spangler et al., 2004). The surgeries are grouped into two classes based on the expected surgery durations. Including OR set up time and anesthesia time, the distribution to represent the Short Procedures is a log normal distribution with a mean of 80 minutes and a standard deviation of 20 minutes. For the Long Procedures, a log normal distribution with a mean of 160 minutes and a standard deviation of 40 minutes is used (Dexter and Tinker, 1995; Zhou and Dexter, 1998; Kharraja et al., 2002). For example, hip replacement (National Health Service, England) and laser eye surgery (LASIK, 2014) can be grouped into short procedure type, while below knee amputation surgery (Iwalk Free, 2016) and oral surgery (Shigeishi, H., Ohta, K., & Takechi, M., 2015) can be grouped into long procedure types. In Case 2, data from CIHI is used to fit distributions for surgery duration to determine if this has an effect on the best scheduling policy. The distributions used are given in Table 2.

Second, multiple types of surgery procedures are examined. In Case 1 and Case 2, two types of procedures (i.e. short and long) are used. In Case 3, one more procedure type, Moderate Procedure, is incorporated. The number of ORs and session length remain the same to investigate the impact of an additional type on the simulation results. The results from simulation models that use existing data (Case 1) are compared to results from models using historical data of the actual durations (Case 2 and Case 3) to investigate the impact of the overall performance.

Third, to determine the effect of emergency cases on performance, a 0% and 10% emergency rate is modeled. It can be seen in Table 2 that the probability of emergency cases occurrence is very low in the data from CIHI. In order to investigate the difference between no emergency cases and emergency cases in simulation results, the study increases the emergency rate to 10% and it is assumed to follow an exponential distribution with a mean of 2 hours (Lamiri et al. 2008).

Fourth, in this study, the cost coefficients for surgeon idle time (c_{it}) and service overtime (c_o) are weighted at five levels: one, five, ten, 15 and 20 relative to patient waiting time. Surgeon satisfaction is a high priority for many hospitals, but patient satisfaction cannot be neglected. The study aims to generate general conclusions that can be applied to many other hospitals that have concern for the surgeon or patient satisfaction.

3.4.2 Appointment Rules

The surgery scheduling problem involves the selection of surgeries to be performed, the allocation of resource time to ORs, and the sequencing of procedures within the allocated time (May et al., 2010). Therefore, determining surgery start time (t_i) is one of the important tasks in surgery scheduling problem. Surgery's start times are decided by the scheduler, so appointment intervals are set in the Arena model.

The study tests two main appointment rules, Fixed Interval rules and Variable Interval rules, commonly found in the appointment scheduling literature (Cayirli et al., 2006; Cayirli et al., 2008; Cayirli et al., 2014). The Fixed Interval (FI) rule has an equal interval between each appointment start time (($t_i - t_{i-1}$). The basic interval usually equals the mean (μ) patient service time, which is followed in this study. In some instances (e.g., when cost coefficients for idle time and overtime are higher), reducing the interval length can improve performance (Saremi et al., 2013; Gul et al., 2011). Thus, variations of the fixed interval rule where the length of time between appointments is less than the mean duration are also tested (see Table 3). For example, FI 1 uses "μ" as an interval that means the interval length between each case is the mean duration of a specified type of surgery. FI 2 uses "$\mu - 5$" which means five minutes less than mean duration is used as the interval length between two cases. In this study, the difference between each interval is set at 5 minutes for Short Procedures, and 10 minutes for Moderate and Long Procedures.

Table 3
Fixed Interval (FI) Rule used in the Three Cases

Interval #	Rule	Interval #	Rule
FI 1	μ	FI 2	$\mu - 5$
FI 3	$\mu - 10$	FI 4	$\mu - 15$
FI 5	$\mu - 20$	FI 6	$\mu - 25$
FI 7	$\mu - 30$	FI 8	$\mu - 35$
FI 9	$\mu - 40$	FI 10	$\mu - 45$
FI 11	$\mu - 50$	FI 12	$\mu - 55$
FI 13	$\mu - 60$	FI 14	$\mu - 65$
FI 15	$\mu - 70$	FI 16	$\mu - 75$

The Variable Interval (VI) rule is also based on the average surgery time for each procedure type. However, while the interval length between each procedure is identical in the fixed interval rule, the interval length is different in the variable interval rule. Several variable interval rules are tested in this study. An Increasing Interval Rule progressively increases the mean surgery duration while a Decreasing Interval Rule progressively shortens the mean surgery duration. In addition, prior literature suggested that a dome pattern in appointment scheduling of an outpatient clinic is the optimal appointment intervals (Robinson and Chen, 2003; Klassen and Yoogalingam, 2009), therefore, this study adopted this insight from outpatient clinic scheduling and extended them to surgery scheduling.

The variable interval rules used in this study are specified in Table 4. There are four types of variable rules used. Variable rules in Case 1 are used as an example to explain the meaning for four types of variable rules here. For Short Procedures, the VI rules are in Table 4. For Long

Procedures, the VI rules are in Table 5. Since fewer Long Procedures can be performed, only Increasing Interval Rule and Decreasing Interval Rule are tested for Long Procedures.

Table 4

Variable Interval (VI) Rule used for Short Procedures in Case 1

Interval #	Dome Rule	Interval #	Reverse Dome Rule
VI 1	70, 75, 80, 75, 70	VI 5	80, 75, 70, 75, 80
VI 2	65, 70, 75, 70, 65	VI 6	75, 70, 65, 70, 75
VI 3	60, 65, 70, 65, 60	VI 7	70, 65, 60, 65, 70
VI 4	55, 60, 65, 60, 55	VI 8	65, 60, 55, 60, 65
	Increasing Interval Rule		**Decreasing Interval Rule**
VI 9	50, 55, 60, 65, 70	VI 13	65, 60, 55, 50, 45
VI 10	55, 60, 65, 70, 75	VI 14	70, 65, 60, 55, 50
VI 11	60, 65, 70, 75, 80	VI 15	75, 70, 65, 60, 55
VI 12	65, 70, 75, 80, 85	VI 16	80, 75, 70, 65, 60

Table 5

Variable Interval Rule (VI) For Long Procedures in Case 1

Interval #	Increasing Interval Rule	Interval #	Decreasing Interval Rule
VI 17	120, 130	VI 20	130, 120
VI 18	110, 120	VI 21	120, 110
VI 19	100, 110	VI 22	110, 100

The ‘Dome’ rules (VI 1 – VI 4) have appointment intervals gradually increasing until the middle of the session, then decreasing. The ‘Reverse Dome’ rules (VI 5 – VI 8) have appointment intervals gradually decreasing until the middle of the session, then increasing. The ‘Increasing Interval’ rules (VI 9 – VI 12, VI 17 – VI 19) have the appointment intervals increasing until the end of the session. The ‘Decreasing Interval’ rules (VI 13 – VI 16, VI 20 –VI 22) have appointment intervals decreasing until the end of the session. As mentioned above, an eight-hour session length is modeled in each OR, and preliminary experiments show that when total OR time is over eight hours (480 minutes), the expected total cost is higher. Therefore, surgery durations of all these rules add up to less or equal to eight hours.

3.4.3 Sequencing Rules

This study considers multiple surgery procedure types. Thus, different sequencing rules are evaluated to determine if this has an impact on performance. The sequencing rules are given in Table 6. The surgery procedure time is denoted by ST where $\{ST(1) < ST(2) < ST(3) \ldots, ST(n)\}$; $ST(1)$ is the shortest procedure while $ST(n)$ is the longest procedure. Prior literature has shown that the Longest Processing Time First (LPT) rule and the Shortest Processing Time First (SPT) rule play an important role in the surgery scheduling problem (Harper, 2002; Sciomachen et al., 2005; Testi et al., 2007). In addition, some alternate rules based on the LPT and SPT rules are investigated in this paper. For AR 1, a long procedure is alternated with a short procedure. AR 2 is the reverse with short procedures alternated with long procedures. AR 3 puts short procedures at the beginning and end of the session and long procedures in the middle. AR 4 shows a reverse pattern with short procedures in the middle.

Table 6

Sequencing Policies

Longest Processing Time First (LPT)	$\{ST(n), \ldots, ST(3), ST(2), S(T1)\}$
Shortest Processing Time First (SPT)	$\{ST(1), ST(2), ST(3) \ldots, ST(n)\}$
Alternate Rule 1 (AR 1)	$\{ST(n), ST(1), ST(n-1), ST(2), \ldots\}$
Alternate Rule 2 (AR 2)	$\{ST(1), ST(n), ST(2), ST(n-1), \ldots\}$
Alternate Rule 3 (AR 3)	$\{ST(1), ST(3), \ldots, ST(n), \ldots, ST(4), ST(2)\}$
Alternate Rule 4 (AR 4)	$\left\{\begin{matrix} ST(n), ST(n-2), \ldots, ST(1), \\ \ldots, ST(n-3), S(Tn-1) \end{matrix}\right\}$

3.4.4 Allocation Rules for Surgery Type

To investigate the impact of different allocations of surgery types on ORs, three scenarios are analyzed for each case: (1) Dedicated ORs, (2) Partially Shared ORs, and (3) Shared ORs.

Scenario 1 evaluates the performance of the system when only one type of surgery is scheduled in each OR. In other words, ORs are dedicated to the same type of surgery procedure. Scenario 2 evaluates the performance when some of the ORs are used by one procedure type and the rest of the ORs can perform different types of surgery procedures. This type of system would represent one where the surgery types are "Partially Shared" by the ORs. Scenario 3 tests the performance when any combination of surgery type can be performed in each OR. This scenario is defined as "Shared ORs". The allocation of surgery types for each scenario is given in Table 7 and Table 8.

Table 7

Case 1 Scenarios

		Number of SP* (80 minutes)	**Number of LP**** (160 minutes)	**SP Duration for Each Room**	**LP Duration for Each Room**	**Total OR Time for Six ORs**
Scenario 1	OR 1 - 2	6		480		480 * 2
	OR 3 - 6		3		480	480 * 4
	Total	**12**	**12**			**2880**
Scenario 2	OR 1 - 3	4	1	320	160	480 * 3
	OR 4 - 6		3		480	480 * 3
	Total	**12**	**12**			**2880**
Scenario 3	OR 1 - 6	2	2	160	320	480 * 6
	Total	**12**	**12**			**2880**

* Short Procedure Duration ~ Lognormal (80, 20)
** Long Procedure Duration ~ Lognormal (160, 40)

The total OR time is 2880 minutes ($6\, ORs \times 480\, minutes$) per session. To allow for consistent comparison across each scenario, the number of the performed cases in 480 minutes for each type procedure in each scenario remains the same. Also, the total OR time is the same across scenarios in each case. Note that the times given in the tables below are average times.

Table 8

Case 2 and Case 3 Scenarios

		Number of SP* (52.9 minutes)	**Number of MP **** (106 minutes)	**Number of LP***** (153 minutes)	**SP Duration for Each Room**	**MP Duration for Each Room**	**LP Duration for Each Room**	**Total OR Time for Six ORs**
Case 2								
Scenario 1	OR 1 - 2	9			477			477 * 2
	OR 3 - 6			3			459	459 * 4
	Total	**18**		**12**				**2790**
Scenario 2	OR 1 - 3	6		1	318		153	471 * 3
	OR 4 - 6			3			459	459 * 3
	Total	**18**		**12**				**2790**
Scenario 3	OR 1 - 6	3		2	159		306	465 * 6
	Total	**18**		**12**				**2790**
Case 3								
Scenario 1	OR 1 - 2	9			477			477 * 2
	OR 3 - 4		4			424		424 * 2
	OR 5 - 6			3			459	459 * 2
	Total	**18**	**8**	**6**				**2720**
Scenario 2	OR 1 - 2		4			424		424 * 2
	OR 3			3			459	459
	OR 4 - 6	6		1	318		153	471 * 3
	Total	**18**	**8**	**6**				**2720**
Scenario 3	OR 1 - 4	4	1	1	212	106	153	471 * 4
	OR 5 - 6	1	2	1	53	212	153	418 * 2
	Total	**18**	**8**	**6**				**2720**

* Short Procedure Duration ~ 30 + Exponential (22.9)
** Moderate Procedure Duration ~ 47 + GAMMA (29.2, 2.03)
*** Long Procedure Duration ~ 44 + 254 * BETA (1.98, 2.62)

Table 9 provides a summary of the factors tested presented by ‘Case’. The distributions and parameter values for each case are given. In addition, the relevant appointment and sequencing rules for each case are specified.

Table 9

Summary of Factors and Rules

Case 1	Distributions/Types	SP *~ Lognormal (80, 20) LP **~ Lognormal (160, 40)
	Probability of emergency cases	0%, 10%
	Appointment rules	FI 1 – FI 5 (SP); FI 1 – FI5 (LP) VI 1 – VI 16 (SP); VI 17 –VI 22 (LP)
	Allocation rules Scenario 1: Dedicated ORs Scenario 2: Partially Shared ORs Scenario 3: Shared ORs	 OR 1 – 2: SP only OR 3 – 6: LP only OR 1 – 3: SP + LP OR 4 – 6: LP only OR 1 – 6: SP + LP
	Sequencing rules Scenario 1: Dedicated ORs Scenario 2: Partially Shared ORs Scenario 3: Shared OR	 OR 1– 6: No Sequencing Rules OR 1 – 3: LPT, SPT, AR3 OR 4 – 6: No Sequencing Rules OR 1– 6: LPT, SPT, AR 1-4
Case 2 (Using CIHI Data)	Distributions/Types	SP ~30 + Exponential (22.9) LP ~ 44 + 254*BETA (1.98, 2.62)
	Probability of emergency cases	0%, 10%
	Appointment rules	FI 1 – FI 5 (SP); FI 1 – FI5 (LP) VI 1 – VI 9 (SP); VI 10 –VI 15 (LP)
	Allocation rules Scenario 1: Dedicated ORs Scenario 2: Partially Shared ORs Scenario 3: Shared ORs	 OR 1 - 2: SP only OR 3 – 6: LP only OR 1 – 3: SP + LP OR 4 – 6: LP only OR 1 – 6: SP + LP
	Sequencing rules Scenario 1: Dedicated ORs Scenario 2: Partially Shared ORs Scenario 3: Shared OR	 OR 1-6: No Sequencing Rules OR 1 – 3: LPT, SPT, AR3 OR 4 – 6: No Sequencing Rules OR 1-6: LPT, SPT, AR 1-4
Case 3 (Using CIHI Data)	Distributions/Types	SP ~ 30 + Exponential (22.9) MP ***~ 47 + GAMMA (29.2, 2.03) LP ~ 44 + 254*BETA (1.98, 2.62)
	Probability of emergency cases	0%, 10%
	Appointment rules	FI 1 – FI 9 (MP) VI 16 – VI 21 (MP)
	Allocation rules Scenario 1: Dedicated ORs Scenario 2: Partially Shared ORs Scenario 3: Shared ORs	OR 1 - 2: SP only OR 3 – 4: MP only OR 3 – 6: LP only OR 1 – 2: MP only OR 3: LP only OR 4 – 6: SP + LP OR 1 – 6: SP + MP + LP
	Sequencing rules Scenario 1: Dedicated ORs Scenario 2: Partially Shared ORs Scenario 3: Shared ORs	 OR 1– 6: No Sequencing Rules OR 1 – 2: No Sequencing Rules OR 3: No Sequencing Rules OR 4 – 6: LPT, SPT, AR1-4 OR 1– 6: LPT, SPT, AR 1-4

*SP ~ Short Procedure
**LP ~ Long Procedure
***MP ~ Moderate Procedure

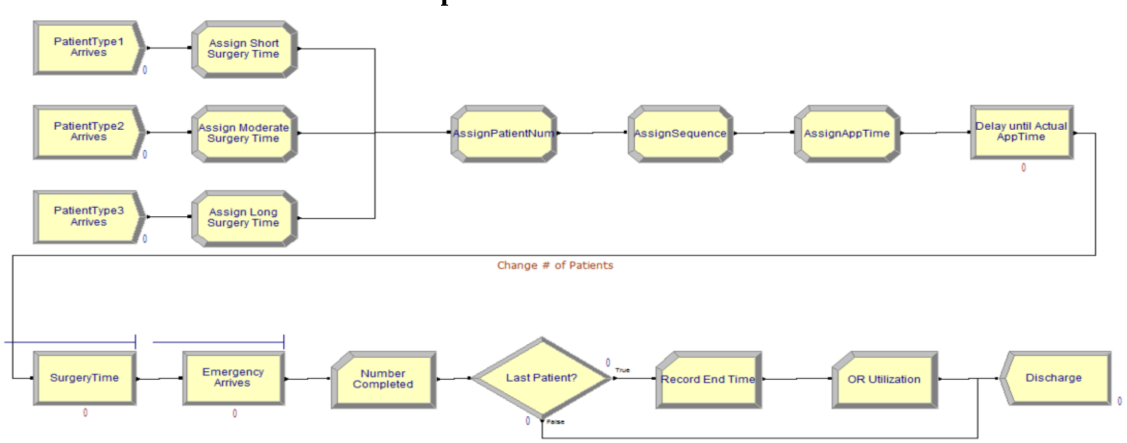
3.4.5 Implementation using Arena

Surgery schedules are simulated using Arena 10.0 for six operating rooms with eight hour OR sessions. A screenshot of the Arena simulation model is shown in Figure 5. Three entity modules represent short procedure patients, moderate procedure patients, and long procedure patients. Each entity is assigned an appointment interval time and sequence. The entity is delayed until either its appointment start time or when the surgeon free (which ever time is greater). Next, a process module captures the surgery procedure being performed. Emergency cases arrive with some probability. If the probability is greater than zero, the emergency procedure is performed. Then the record module records the end time of the day and the OR utilization. After that, the entity is disposed. For each case, 3 Scenarios × 5 Cost coefficient values × 2 Probabilities for emergency cases were run. Additionally, relevant FI and VI rules were tested for each case. Five hundred replications are performed for each experiment.

To verify the simulation model, firstly, deterministic data instead of distribution is used for both patient arrival time and surgery processing time. Secondly, a single entity enters the model, and then followed this entity through all the nodes to ensure the simulation system’s logic correct.

Figure 5

Snapshot of Arena Model



4. Results and Analysis

In this section, the results for the three cases mentioned above are presented and discussed in Section 4.1, Section 4.2 and Section 4.3, respectively. A summary of the scenarios, factors, and rules tested are provided for each case at the beginning of each section. The distributions and parameter values for each case and the relevant appointment and sequencing rules for each case are also specified. The results where the probability of emergency arrivals is zero ($P_E = 0\%$) are presented first followed by the results where the probability of emergency arrivals is 10% ($P_E = 10\%$). All results (i.e. waiting time, idle time and overtime) are in 'minutes'. The key findings from each case are summarized at the end of each section.

4.1 Case 1: Two Procedure Types

In Case 1, the distributions from the prior literature are used, and two procedure types within three scenarios and six ORs are examined. Different appointment rules, allocation rules, and sequencing rules are tested. Detailed factors and rules are given in Table 10. Completed simulation results for all FI and VI rules are given in Appendix A Table A 1– Table A 3 for 0% emergency rate and Table A 4 – Table A 5 for 10% emergency rate. After the analysis of the simulation results, a One-way ANOVA, with $\alpha = 0.05$, was conducted to determine whether there is a statistically significant difference among the appointment rules and sequencing rules. The ANOVA results are provided in Appendix B Table B 1–Table B 12 for 0% emergency rate and Table B 13 –Table B 24 for 10% emergency rate.

Table 10

Summary of factors and rules for Case 1

Distributions/Types	SP *~ Lognormal (80, 20) LP **~ Lognormal (160, 40)
Probability of emergency cases	0%, 10%
Appointment rules	SP: FI 1 – FI 5 VI 1 – VI 16 LP: FI 1 – FI5 VI 17 –VI 22
Allocation rules Scenario 1: Dedicated ORs Scenario 2: Partially Shared ORs Scenario 3: Shared ORs	 OR 1 – 2: 6 SP only OR 3 – 6: 3 LP only OR 1 – 3: 4 SP + 1 LP OR 4 – 6: 3 LP only OR 1 – 6: 2 SP +2 LP
Sequencing rules Scenario 1: Dedicated ORs Scenario 2: Partially Shared ORs Scenario 3: Shared OR	 OR 1 - 6: No Sequencing Rules OR 1 – 3: LPT, SPT, AR3 OR 4 – 6: No Sequencing Rules OR 1 – 6: LPT, SPT, AR 1-4

*SP ~ Short Procedure
**LP ~ Long Procedure

4.1.1 Case 1 Scenario 1 Dedicated ORs with No Emergency Cases

Scenario 1, "Dedicated ORs", evaluates the performance of the system when all ORs are dedicated to the same type of surgery procedure. The fixed interval rules in Table 3 and each set of variable interval rules in Table 4 and Table 5 are tested to determine which one would have better results. The best rules are selected and analyzed in this section.

A comparison of the results for Short Procedure shows that, in general, as the cost coefficient of idle time and overtime increases, the intervals between appointments should be decreased. Decreasing the length between start times of each surgery results in a higher patient waiting time, but lower surgeon idle time and service overtime. For example, when the cost coefficient of waiting time, idle time and overtime are equal to one, FI 1 provides the best results in terms of expected total cost 148.6 (± 9.949) compared to other rules. This is intuitive, as allowing a larger interval length between cases will always reduce waiting time for next patient because the previous surgery will have more time to be finished and will be less likely to affect the start time of the next surgery. However, the case where waiting time, idle time and overtime are equally weighted is unlikely to happen in practice. Hospitals rarely consider the cost of surgeon idle time and overtime to be the same as the cost of patient waiting time due to the high hospital expenditures. Thus, the results for representative cases where c_{it}, c_o are equal to five, ten and 15 are presented in Table 11 and Table 12 and discussed. A cost coefficient of five is used for comparison as a low weight. A cost coefficient of ten is used for comparison as a moderate weight. In addition, it can be seen in Appendix A Table A 1 (Short Procedures) and Table A 3 (Long Procedures) that the best rules are similar for cost coefficient 15 and 20. Therefore, only a cost coefficient of 15 is used for the comparison as a high weight.

In Table 11, the best schedule for each set of rules tested (FI, Dome, Reverse Dome, Increasing Interval and Decreasing Interval) is presented. For FI Rules, when c_{it}, $c_o = 5$, FI 2 produces the lowest total expect cost (333.50 ± 21.86). When c_{it}, $c_o = 10$, the lowest expected total cost happens with FI 3 (489.65 ± 37.38). FI 4 is the best option (624.03 ± 52.54) when c_{it}, $c_o = 15$.

According to the results, the Increasing Interval Rules, VI 12 and VI 11, provide the best overall performance when the cost coefficients for idle time and overtime are five, ten and 15 with expected total costs of 316.32 ± 22.10, 464.37 ± 37.51, 590.81 ± 51.35, respectively. The best rules are the same (VI 11) when c_{it}, $c_o = 10$ and c_{it}, $c_o = 15$. The Dome Rules, VI 1, VI 2 and VI 3, have the second lowest expected total cost compared to other rules. It should be noted that the Reverse Dome Rule and Decreasing Interval Rule tend to perform worse since they generate higher idle time and overtime for the surgeon.

Table 11

Scenario 1, Comparison of Best Rule in FI and VI for Short Procedures (c_{it}, c_o= 5, 10, 15)

	Fixed Interval	Dome	Reverse Dome	Increasing Interval	Decreasing Interval
Performance Measure	**Average, 95% C.I.**				
c_{it}, c_o= 5					
	FI 2	**VI 1**	**VI 5**	**VI 12**	**VI 16**
Total Waiting Time (min)	130.59 ± 9.97	135.56 ± 10.20	128.51 ± 9.76	153.08 ± 11.10	164.90 ± 10.10
Total Idle Time (min)	15.01 ± 1.55	13.05 ± 1.49	17.59 ± 1.61	10.02 ± 1.38	14.97 ± 1.39
Overtime (min)	25.57 ± 2.97	24.47 ± 2.93	27.11 ± 3.03	22.62 ± 2.89	26.77 ± 3.04
Utilization	0.97 ± 0.00	0.97 ± 0.00	0.96 ± 0.00	0.98 ± 0.00	0.97 ± 0.00
WT5IT5OT	333.50 ± 21.86	323.12 ± 21.75	352.05 ± 22.10	316.32 ± 22.10	373.57 ± 23.03
c_{it}, c_o= 10					
	FI 3	**VI 2**	**VI 7**	**VI 11**	**VI 15**
Total Waiting Time (min)	180.85 ± 11.30	188.11 ± 11.56	233.89 ± 11.89	211.48 ± 12.32	215.40 ± 11.13
Total Idle Time (min)	7.82 ± 1.04	6.33 ± 0.97	5.42 ± 0.80	3.93 ± 0.78	9.03 ± 1.06
Overtime (min)	23.06 ± 2.93	22.28 ± 2.90	22.55 ± 2.93	21.36 ± 2.87	24.16 ± 2.97
Utilization	0.98 ± 0.00	0.99 ± 0.00	0.99 ± 0.00	0.99 ± 0.00	0.98 ± 0.00
WT10IT10OT	489.65 ± 37.38	474.22 ± 37.07	513.55 ± 38.46	464.37 ± 37.51	547.24 ± 38.42
c_{it}, c_o= 15					
	FI 4	**VI 3**	**VI 7**	**VI 11**	**VI 14**
Total Waiting Time (min)	240.58 ± 12.25	249.69 ± 12.53	233.89 ± 11.89	211.48 ± 12.32	273.62 ± 11.93
Total Idle Time (min)	3.76 ± 0.68	2.59 ± 0.59	5.42 ± 0.80	3.93 ± 0.78	5.22 ± 0.77
Overtime (min)	21.81 ± 2.90	21.33 ± 2.87	22.55 ± 2.93	21.36 ± 2.87	22.55 ± 2.93
Utilization	0.99 ± 0.00	0.99 ± 0.00	0.99 ± 0.00	0.99 ± 0.00	0.99 ± 0.00
WT15IT15OT	624.03 ± 52.54	608.47 ± 52.38	653.38 ± 52.91	590.81 ± 51.35	690.18 ± 53.07

In a comparison of FI rules and VI rules (i.e. Dome Rule, Reverse Dome Rule, Increasing Interval Rule and Decreasing Interval Rule) across three different cost coefficients (i.e. five, ten and 15), all Post hoc test (Tukey HSD) results show that the difference in performance is not statistically significant, thus validating that the fixed interval rules and the variable interval rules are not significantly different in producing lower expected total cost for Short Procedures.

However, when c_{it}, $c_o = 5$, there is a statistically significant difference between Increasing Interval Rule (VI 12, 316.32 ± 22.10) and Decreasing Interval Rule (VI 16, 373.32 ± 23.03) ($p = 0.003$). When c_{it}, $c_o = 10$, there is still a significant difference between these two rules ($p = 0.019$). When c_{it}, $c_o = 15$, there is no statistically significant difference between them ($p = 0.064$). The ANOVA results are shown in Appendix B Table B 1 to Table B 3.

The results for the best fixed and variable interval rules found for Long Procedures are given in Table 12. Complete results are given in Appendix A. The results show that as the cost coefficient of idle time and overtime increases, the intervals should be decreased to get a lower expected total cost. When the intervals between appointments decrease, idle time and overtime decrease while the waiting time increases. When the cost coefficients of idle time and overtime is five, FI 7 provides the best performance in terms of expected total cost (274.5 ± 25.78). FI 9 (439.33 ± 47.05) and FI 11 (596.85 ± 68.34) have lower expected total cost when the cost coefficients of idle time and overtime are ten and 15 respectively.

Since only three Long Procedures are performed, the Dome Rule and Reverse Dome Rule are not applicable since the number of procedures is too small. When c_{it}, $c_o = 5$, VI 17 has lowest expected total cost (273.27 ± 26.19). When c_{it}, $c_o = 10$, VI 17 has lowest expected total cost (438.15 ± 46.74). When c_{it}, $c_o = 15$, VI 18 performs best in overall performance (591.17 ± 68.18). It can be noted that, the Increasing Interval Rule (VI 17 and VI 18) produce best results when the cost coefficients for idle time and overtime are five, ten and 15. This finding is consistent with the finding in the Short Procedures.

Table 12

Scenario 1, Comparison of Best Rule in FI and VI for Long Procedures (c_{it}, c_o= 5, 10, 15)

	Fixed Interval	**Increasing Interval**	**Decreasing Interval**
Performance Measure	**Average, 95% C.I.**		
c_{it}, c_o= 5			
	FI 7	**VI 17**	**VI 20**
Total Waiting Time (min)	93.26 ± 7.04	108.38 ± 7.41	102.36 ± 7.13
Total Idle Time (min)	6.51 ± 1.17	3.89 ± 0.89	5.60 ± 1.04
Overtime (min)	29.75 ± 4.24	29.09 ± 4.22	29.70 ± 4.24
Utilization	0.99 ± 0.00	0.99 ± 0.00	0.99 ± 0.00
WT5IT5OT	274.55 ± 25.78	273.27 ± 26.18	278.84 ± 26
c_{it}, c_o= 10			
	FI 9	**VI 17**	**VI 21**
Total Waiting Time (min)	117.62 ± 7.50	108.38 ± 7.41	127.23 ± 7.55
Total Idle Time (min)	3.13 ± 0.76	3.89 ± 0.89	2.74 ± 0.69
Overtime (min)	29.04 ± 4.23	29.09 ± 4.22	29.03 ± 4.23
Utilization	0.99 ± 0.00	0.99 ± 0.00	0.99 ± 0.00
WT10IT10OT	439.33 ± 47.05	438.15 ± 46.74	444.97 ± 47.22
c_{it}, c_o= 15			
	FI 11	**VI 18**	**VI 21**
Total Waiting Time (min)	144.64 ± 7.77	134.91 ± 7.74	127.23 ± 7.55
Total Idle Time (min)	1.41 ± 0.45	1.6781 ± 0.52	2.74 ± 0.69
Overtime (min)	28.74 ± 4.22	28.74 ± 4.22	29.03 ± 4.23
Utilization	1.00 ± 0.00	1.00 ± 0.00	0.99 ± 0.00
WT15IT15OT	596.85 ± 68.34	591.17 ± 68.18	603.84 ± 68.07

In a comparison of FI rules and VI rules (i.e. Increasing Interval Rule and Decreasing Interval Rule) across three different cost coefficients (i.e. five, ten and 15), all Post hoc test (Tukey HSD) results show that the difference in performance is not statistically significant, thus validating that the simulation model can use either the fixed interval rules or the variable interval rules to produce a lower expected total cost for Long Procedures. In addition, results are not statistically significant between the Increasing Interval Rule and Decreasing Interval Rule for Long Procedures. The results are in Appendix B Table B 4 to Table B 6.

4.1.2 Case 1 Scenario 2 Partially Shared ORs with No Emergency Cases

Scenario 2, "Partially Shared ORs", evaluates performance when some of the ORs are occupied by one procedure type and some are allocated multiple procedure types. Since different types of procedures can be performed in an OR, a decision also has to be made on how to sequence these procedures. The LPT, SPT, and AR 3 sequencing rules are tested in this scenario. The AR 1, the AR 2 and the AR 4 rules are not applicable since there is only one Long Procedure in this scenario.

For Scenario 1, where ORs were dedicated to a single procedure type, the ANOVA results showed that the fixed interval rule and the variable interval rule are not significantly different in getting the lower expected total cost. In order to keep the analysis of results brief, for Scenario 2, only the best FI rules from Scenario 1 are tested.

A comparison of results is shown in Table 13. Scheduling all Short Procedures before the Long Procedures (SPT) proved to be more effective in lowering waiting time than putting the Long Procedures before the Short Procedures (LPT) or putting the Long Procedures in the middle of the queue (AR 3) for all cost coefficients levels. The LPT rule results in lowest idle time for all three coefficients values (7.96 ± 1.33 minutes, 3.40 ± 0.81 minutes, and 1.29 ± 0.47 minutes respectively). For overtime, the LPT rule also performs better, with 24.63 ± 3.23 minutes, 23.93 ± 3.22 minutes and 23.67 ± 3.22 minutes for cost coefficient five, ten and 15 for overtime. However, it should be noted that the LPT rule only surpasses other two rules by less than 4 minutes for idle time and overtime. The average waiting time for LPT is the highest compared to the other rules using three different cost coefficients. An ideal sequencing policy can minimize the tradeoff between waiting time, idle time and overtime, making the LPT rule not an ideal policy. For AR 3, even though its waiting time is not as high as the one resulted by the LPT rule, its relatively high idle time and overtime make the AR 3 a rule with the highest expected total cost.

Table 13

Scenario 2, Comparison of Sequencing Rules (c_{it}, c_o= 5, 10, 15)

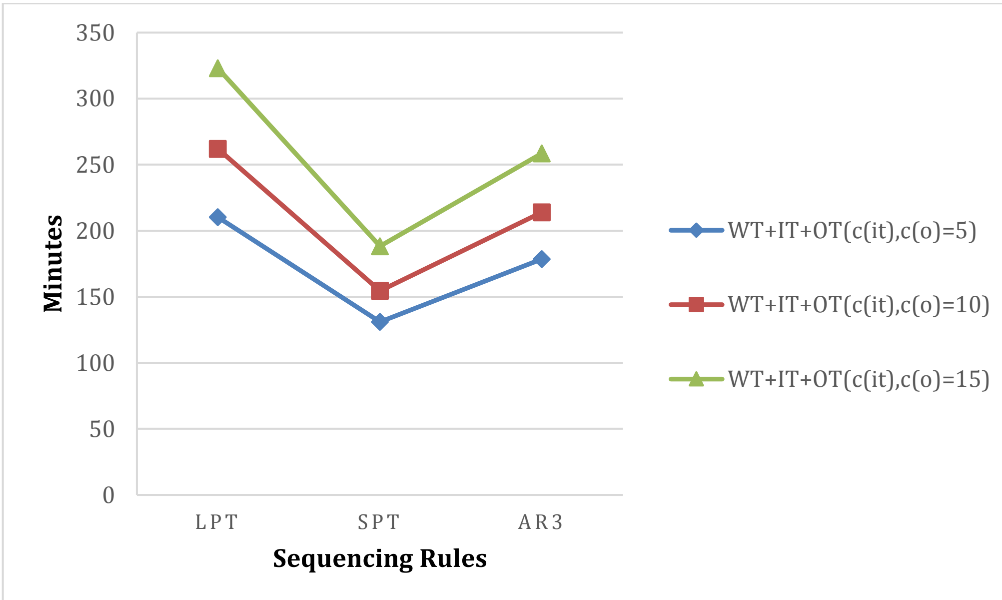
	LPT	**SPT**	**AR3**
Performance Measure	**Average, 95% C.I.**		
c_{it}, c_o= 5			
Total Waiting Time (min)	177.67 ± 12.93	88.53 ± 7.35	137.89 ± 9.06
Total Idle Time (min)	7.96 ± 1.33	13.74 ± 1.44	12.76 ± 1.40
Overtime (min)	24.63 ± 3.23	28.72 ± 3.41	27.81 ± 3.41
Utilization	0.98 ± 0	0.97 ± 0	0.97 ± 0
WT5IT5OT	340.62 ± 25.81	300.85 ± 20.96	340.76 ± 23.98
c_{it}, c_o= 10			
Total Waiting Time (min)	234.71 ± 14.04	120.98 ± 8.3	180.98 ± 9.9
Total Idle Time (min)	3.40 ± 0.81	7.40 ± 1.01	7.034 ± 0.97
Overtime (min)	23.93 ± 3.22	26.09 ± 3.34	25.93 ± 3.34
Utilization	0.99 ± 0	0.98 ± 0	0.99 ± 0
WT10IT10OT	507.93 ± 42.65	455.82 ± 38	510.63 ± 40.97
c_{it}, c_o= 15			
Total Waiting Time (min)	298.01 ± 14.72	159.77 ± 9.01	230.16 ± 10.5
Total Idle Time (min)	1.29 ± 0.47	3.67 ± 0.67	3.6 ± 0.63
Overtime (min)	23.67 ± 3.22	24.88 ± 3.29	24.81 ± 3.28
Utilization	1.00 ± 0	0.99 ± 0	0.99 ± 0
WT15IT15OT	672.44 ± 59.53	587.98 ± 54.42	656.53 ± 57.30

According to the results, it can be seen that, what really differentiates these three rules is the waiting time. The SPT rule showed lower in waiting time than the other two rules when c_{it}, c_o= 5 (88.53 ± 7.35 minutes), c_{it}, c_o= 10 (120.98 ± 8.3 minutes) or c_{it}, c_o= 15 (159.77 ± 9.01 minutes).

Therefore, the SPT rule is the best rule in terms of overall performance and waiting time. The line graph Figure 6 (c_{it}, c_o= 5, 10, 15) shows a more intuitive comparison.

Figure 6

Scenario 2 Comparison of Sequencing Rules (c_{it}, c_o= 5, 10, 15)



In a comparison of these three sequencing rules, when c_{it}, c_o= 5, Post hoc test (Tukey HSD) reveals that the expected total cost is statistically significantly lower with the SPT rule (300.85 ± 20.96, $p = 0.050$) compared to the AR 3 (340.76 ± 23.98). There is no statistically significant difference between the LPT rule and other two rules. In addition, the difference in performance is not statistically significant when c_{it}, c_o= 10 and when c_{it}, c_o= 15. The ANOVA comparison results are in Appendix B Table B 7 to Table B 9. Even though the overall performance between three rules are not significantly different when the cost coefficient is higher, the waiting time of the SPT rule is the lowest and the waiting time of the LPT rule is the highest. Therefore, in terms of overall performance, it appears better to avoid the LPT rule and AR 3 when there are only two procedure types in the same OR.

4.1.3 Case 1 Scenario 3 Shared ORs with No Emergency Cases

Scenario 3, “Shared ORs”, tests the performance when all ORs are allocated different procedure types. (1) LPT rule, (2) SPT rule, (3) AR 1, (4) AR 2, (5) AR 3 and (6) AR 4 are tested in this scenario. Similar to Scenario 2, the best FI rules from Scenario 1 are used.

The comparison of results is in Table 14. The line graph is in Figure 7. The SPT rule is the best option in this scenario. When the cost coefficient of idle time and overtime is five, the SPT rule results in lowest patient waiting time (80.37 ± 5.98 minutes) but highest idle time (11.65 ± 1.28 minutes). However, when the SPT rule is used, there is an improvement in waiting time, making it the most ideal policy out of those investigated (300.02 ± 23.92). The differentiating factor is again the waiting time of patients.

The LPT rule has highest expected total cost (355.29 ± 29.77) due to its highest waiting time (184.62 ± 12.38 minutes). Even though it has the lowest idle time (5.41 ± 1.07 minutes), it still cannot offset the cost from waiting time. In terms of the four alternated rules, AR 2 (313.59 ± 25.81) and AR 4 (311.90 ± 26.66) result in lower expected total cost than AR 1 (336.23 ± 28.01) and AR 3 (338.76 ± 27.2). When c_{it}, c_o= 10 or c_{it}, c_o= 15, the findings are similar that the SPT rule is still the best option compared to the LPT rule and the four alternated rules.

Table 14

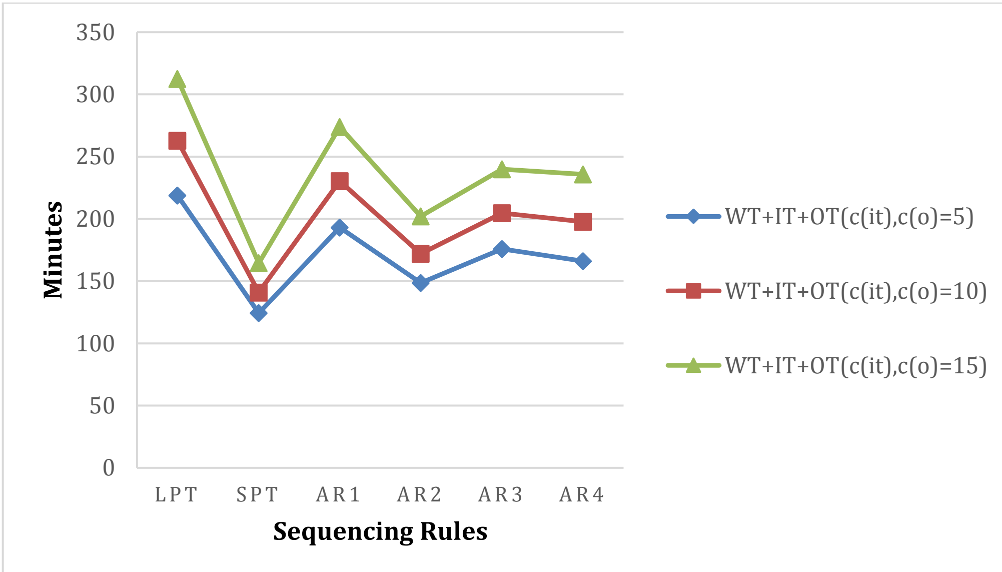
Scenario 3, Comparison of Sequencing Rules (c_{it}, c_o= 5, 10, 15)

	LPT	SPT	AR1	AR2	AR3	AR4
Performance Measure	**Average, 95% C.I.**					
c_{it}, c_o= 5						
Total Waiting Time (min)	184.62 ± 12.38	80.37 ± 5.98	157.39 ± 10.98	107.35 ± 8.17	135.14 ± 8.71	129.72 ± 10.49
Total Idle Time (min)	5.41 ± 1.07	11.65 ± 1.28	6.63 ± 1.21	9.95 ± 1.21	9.68 ± 1.19	7.02 ± 1.22
Overtime (min)	28.72 ± 3.91	32.28 ± 4.07	29.13 ± 3.92	31.29 ± 4.05	31.04 ± 4.05	29.42 ± 3.92
Utilization	0.99 ± 0	0.98 ± 0	0.99 ± 0	0.98 ± 0	0.98 ± 0	0.98 ± 0
WT5IT5OT	355.29 ± 29.77	300.02 ± 23.92	336.23 ± 28.01	313.55 ± 25.81	338.76 ± 27.2	311.90 ± 26.66
c_{it}, c_o= 10						
Total Waiting Time (min)	232.19 ± 12.96	104.20 ± 6.55	199.08 ± 11.67	136.86 ± 8.75	169.78 ± 9.23	166.14 ± 11.24
Total Idle Time (min)	2.40 ± 0.65	6.50 ± 0.92	3.08 ± 0.76	5.44 ± 0.83	5.30 ± 0.82	3.21 ± 0.77
Overtime (min)	28.15 ± 3.91	30.25 ± 4.01	28.30 ± 3.91	29.67 ± 4	29.59 ± 4	28.39 ± 3.91
Utilization	0.99 ± 0	0.99 ± 0	0.99 ± 0	0.99 ± 0	0.99 ± 0	0.99 ± 0
WT10IT10OT	537.68 ± 49.64	471.61 ± 44.02	512.89 ± 47.82	487.96 ± 45.95	518.70 ± 47.4	482.00 ± 46.45
c_{it}, c_o= 15						
Total Waiting Time (min)	283.52 ± 13.3	131.90 ± 6.98	244.59 ± 12.11	170.34 ± 9.13	208.39 ± 9.57	206.55 ± 11.71
Total Idle Time (min)	1.00 ± 0.37	3.41 ± 0.62	1.25 ± 0.44	2.84 ± 0.54	2.83 ± 0.55	1.27 ± 0.43
Overtime (min)	27.94 ± 3.91	29.10 ± 3.97	27.99 ± 3.91	28.80 ± 3.97	28.79 ± 3.97	28.02 ± 3.91
Utilization	1.00 ± 0	0.99 ± 0	1.00 ± 0	0.99 ± 0	0.99 ± 0	1.00 ± 0
WT15IT15OT	717.57 ± 69.58	619.58 ± 63.72	683.14 ± 67.93	644.90 ± 65.77	682.55 ± 67.23	645.89 ± 66.55

In a comparison of these six sequencing rules, when c_{it}, c_o= 5, Post hoc tests (Tukey HSD) results are statistically different only between the LPT rule (355.29 ± 29.77, $p = 0.049$) and the SPT rule (300.02 ± 23.92). When the idle time and overtime are weighted more, the difference in performance is not statistically significant between these rules thus it can be said that changing sequencing rules in scenarios 3 would not result in a significant improvement in overall performance. The ANOVA results are in Appendix B Table B 10 to Table B 12.

Figure 7

Scenario 3 Comparison of Sequencing Rules (c_{it}, c_o= 5, 10, 15)



4.1.4 Case 1 Comparison of Three Scenarios with No Emergency Cases

To allow for consistent comparison across each scenario, the number of the processed surgeries for each procedure type and therefore, the total OR time in each scenario is the same. Also, in terms of consistent comparison, in dedicated ORs, the FI appointment scheduling rules are used. In partially shared ORs and shared ORs, the SPT sequencing rule and FI appointment scheduling rules are tested.

The expected total costs for each scenario for all six ORs are shown in Table 15 for cost coefficients levels of five, ten and 15. Scenario 2, “Partially Shared ORs”, always has the lowest expected total cost with 1726.2 when c_{it}, c_o= 5, 2685.45 when c_{it}, c_o= 10, and 3560.49 when c_{it}, c_o= 15. Thus, an allocation rule that dedicates some ORs to a single procedure type and remaining ORs to multiple surgery types may improve performance.

Table 15

Expected total cost for Case 1 (c_{it}, c_o= 5, 10, 15)

		Short Procedures (80 Minutes)	Long Procedures (160 Minutes)	Total OR Time	Expected Total Cost $c_{it}, c_o = 5$	Expected Total Cost $c_{it}, c_o = 10$	Expected Total Cost $c_{it}, c_o = 15$
Scenario 1	OR 1 - 2	6		480 * 2	333.50 * 2	489.65 * 2	624.03* 2
	OR 3 - 6		3	480 * 4	274.55 * 4	439.33 * 4	598.85* 4
	Total			**2880**	**1765.2**	**2736.62**	**3643.46**
Scenario 2	OR 1 - 3	4	1	480 * 3	300.85 * 3	455.82 * 3	587.98* 3
	OR 4 - 6		3	480 * 3	274.55 * 3	439.33 * 3	598.85 * 3
	Total			**2880**	**1726.2**	**2685.45**	**3560.49**
Scenario 3	OR 1 - 6	2	2	480 * 6	300.02 * 6	471.61 * 6	619.58 * 6
	Total			**2880**	**1800.12**	**2829.66**	**3717.48**

4.1.5 Case 1 Scenario 1 Dedicated ORs with Emergency Cases

The probability of emergency arrivals is set at 10% emergency rate. Pretesting shows that “Dome Rule” and “Increasing Interval Rule” outperform than “Reverse Dome Rule” and “Decreasing Interval Rule” in term of lower expected total cost. Therefore, the results in this section eliminate those that used “Reverse Dome Rule” and “Decrease Interval Rule”. It should be noted that the utilization of all results is very high after adding the emergency cases.

Some of the conclusions are similar to those in Section 4.1.1. As the cost coefficient of idle time and overtime increases, the intervals should be decreased to get a lower expected total cost. The waiting time and utilization increases while the interval of appointment time decreases. Decreasing the length between start times of each surgery would result in a higher patient waiting time, but lower surgeon idle time and service overtime.

Table 16

Scenario 1, Comparison of Best Rule in FI and VI for Short Procedures ((c_{it}, c_o= 5, 10, 15)

	Fixed Interval	**Dome Rule**	**Increasing Interval**
Performance Measure	**Average, 95% C.I.**		
c_{it}, c_o= 5			
	FI 2	**VI 1**	**VI 11**
Total Waiting Time (min)	254.98 ± 26.14	259.49 ± 25.70	275.76 ± 25.86
Total Idle Time (min)	12.05 ± 1.44	10.3 ± 1.37	7.40 ± 1.21
Overtime (min)	88.52 ± 10.04	87.27 ± 10.02	85.20 ± 10.01
Utilization	1.00 ± 0	1.0 ± 0	1.00 ± 0
WT5IT5OT	757.83 ± 69.72	747.32 ± 69.20	738.75 ± 69.52
c_{it}, c_o= 10			
	FI 3	**VI 2**	**VI 10**
Total Waiting Time (min)	302.72 ± 26.24	309.88 ± 26.14	331.21 ± 26.23
Total Idle Time (min)	6.57 ± .99	5.17 ± 0.9	3.04 ± 0.7
Overtime (min)	85.70 ± 10.03	84.79 ± 10.02	83.67 ± 10
Utilization	1.00 ± 0	1.00 ± 0	1.00 ± 0
WT10IT10OT	1225.39 ± 118.85	1209.47 ± 118.79	1198.34 ± 119.16
c_{it}, c_o= 15			
	FI 4	**VI 4**	**VI 10**
Total Waiting Time (min)	358.45 ± 26.33	383.91 ± 26.21	331.21 ± 26.23
Total Idle Time (min)	3.37 ± .66	1.29 ± 0.4	3.04 ± 0.7
Overtime (min)	84.18 ± 10.02	83.1 ± 9.99	83.67 ± 10
Utilization	1.00 ± 0	1.00 ± 0	1.00 ± 0
WT15IT15OT	1671.8 ± 168.71	1649.74 ±168.85	1631.9 ± 168.34

The results for best fixed and variable interval rules for Short Procedures are given in Table 16. FI 2, FI 3 and FI 4 have the best results when c_{it}, c_o= 5, 10 and 15 with 757.83 ± 69.72, 1225.39 ± 118.85, 1671.8 ± 168.71 respectively. For Increasing Interval Rule, VI 11 results in lowest expected total cost when c_{it}, c_o= 5, with 738.75 ± 69.52. VI 10 produces the best overall performance when c_{it}, c_o= 10 and 15, with 1198.34 ± 119.16 and 1631.9 ± 168.34 respectively.

As shown in Appendix B Table B 13 to Table B 15, in a comparison of FI rules and VI rules (i.e. Dome Rule and Increasing Interval Rule) across three different cost coefficients (i.e. five, ten and 15), all Post hoc test (Tukey HSD) results indicate that the difference in performance is not statistically significant. Therefore, the fixed interval rules and the variable interval rules are not significantly different in producing lower expected total cost for Short Procedures.

The results for best fixed and variable interval rules for Long Procedures are given in Table 17. When c_{it}, c_o= 5, FI rule (FI 7) provides the best performance in terms of expected total cost (418.86 ± 43.77). When c_{it}, c_o= 10 and 15, the Increasing Interval Rule (VI 18) produces best results, with 707.77 ± 81.37 and 987.89 ± 119.39 respectively.

Since there are two groups (i.e. FI rule and Increasing Interval rule) in the experiments, a t test was conducted to test whether the simulation results between experiments are significantly different. The results are provided in the Appendix B Table B 16 to Table B 18. In a comparison of the Fixed Interval Rule versus the Variable Interval Rule, regarding the cost coefficient of five, ten and 15 for idle time and overtime, the difference in performance is not statistically significant, thus validating that there is no statistically difference between them. This finding is similar to the finding in Section 4.1.1.

Table 17

Scenario 1, Comparison of Best Rule in FI and VI for Long Procedures (c_{it}, c_o= 5, 10, 15)

	Fixed Interval	Increasing Interval
Performance Measure	**Average, 95% C.I.**	
c_{it}, c_o= 5		
	FI 7	**VI 18**
Total Waiting Time (min)	110.98 ± 8.99	147.55 ±8.75
Total Idle Time (min)	6.00 ± 1.15	1.60 ±0.52
Overtime (min)	55.58 ± 7.71	54.42 ±7.67
Utilization	1.00 ± 0	1.00 ± 0
WT5IT5OT	418.86 ± 43.77	427.66 ±43.54
c_{it}, c_o= 10		
	FI 9	**VI 18**
Total Waiting Time (min)	130.40 ± 8.57	147.55 ±8.75
Total Idle Time (min)	2.96 ± 0.75	1.60 ±0.52
Overtime (min)	54.78 ± 7.68	54.42 ±7.67
Utilization	1.00 ± 0	1.00 ± 0
WT10IT10OT	707.82 ± 81.13	707.77 ±81.37
c_{it}, c_o= 15		
	FI 11	**VI 18**
Total Waiting Time (min)	157.25 ± 8.78	147.55 ±8.75
Total Idle Time (min)	1.33 ± 0.45	1.60 ±0.52
Overtime (min)	54.40 ± 7.67	54.42 ±7.67
Utilization	1.00 ± 0	1.00 ± 0
WT15IT15OT	993.24 ± 119.49	987.89 ±119.39

4.1.6 Case 1 Scenario 2 Partially Shared ORs with Emergency Cases

In a comparison of the LPT, SPT and AR 3 rules, the SPT rule results in the lowest expected total. The comparisons are shown in Table 18. When c_{it}, c_o= 5, the lowest expected total cost is 572.70 ± 54.57 and the lowest patient waiting time is 153.71 ± 16.82 minutes, with the SPT rule. But it has the highest idle time (11.29 ± 1.35 minutes) and overtime (72.51 ± 8.78 minutes). The LPT rule has the lowest idle time (6.46 ± 1.20) and overtime (69.58 ± 8.90 minutes). Due to the highest waiting time (230.46 ± 17.77 minutes), the LPT rule gets the highest expected total cost (610.67 ± 56.16). When the cost coefficient increases to ten and 15, the SPT rule still performs best compared to other rules. Visual comparisons of the sequencing rules can be seen in Figure 8.

Table 18

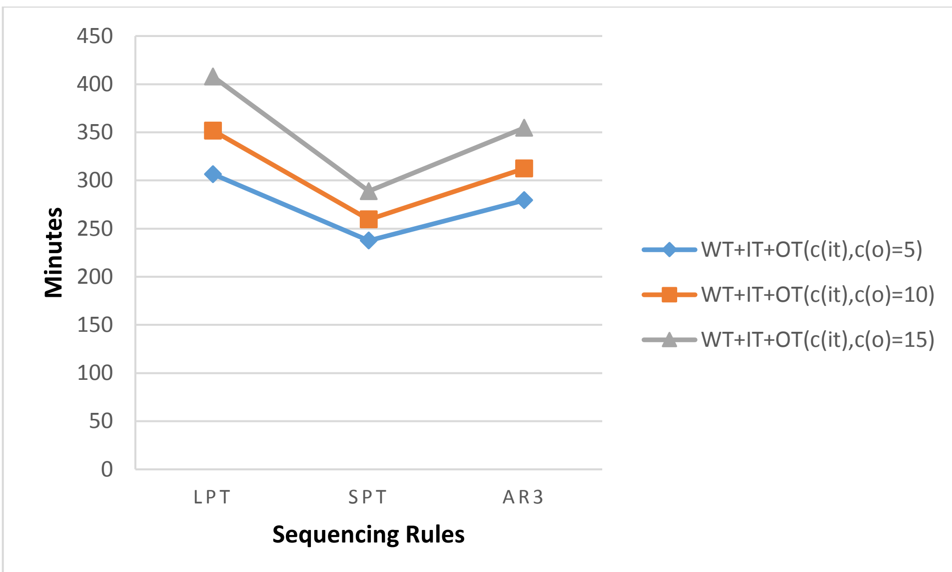
Scenario 2, Comparison of Sequencing Rules (c_{it}, c_o= 5, 10, 15)

	LPT	SPT	AR3
Performance Measure	**Average, 95% C.I.**		
c_{it}, c_o= 5			
Total Waiting Time (min)	230.46 ± 17.77	153.71 ± 16.82	197.17 ± 17.43
Total Idle Time (min)	6.46 ± 1.20	11.29 ± 1.35	10.60 ± 1.29
Overtime (min)	69.58 ± 8.90	72.51 ± 8.78	71.85 ± 8.78
Utilization	1.00 ± 0	1.00 ± 0	1.00 ± 0
WT5IT5OT	610.67 ± 56.16	572.70 ± 54.57	609.45 ± 55.55
c_{it}, c_o= 10			
Total Waiting Time (min)	280.50 ± 17.74	183.38 ± 16.73	236.92 ± 17.59
Total Idle Time (min)	2.83 ± 0.74	6.32 ± 0.95	6.01 ± 0.9
Overtime (min)	68.33 ± 8.88	69.71 ± 8.76	69.54 ± 8.74
Utilization	1.00 ± 0	1.00 ± 0	1.00 ± 0
WT10IT10OT	992.02 ± 99.44	943.71 ± 97.15	992.40 ± 98.24
c_{it}, c_o= 15			
Total Waiting Time (min)	338.89 ± 17.31	217.44 ± 16.73	283.24 ± 17.75
Total Idle Time (min)	1.11 ± 0.45	3.24 ± 0.63	3.17 ± 0.6
Overtime (min)	67.73 ± 8.86	68.23 ± 8.72	68.14 ± 8.71
Utilization	1.00 ± 0	1.00 ± 0	1.00 ± 0
WT15IT15OT	1371.57 ±143.03	1289.44 ±139.98	1352.94 ± 141.43

In a comparison of the LPT, SPT and AR 3 rules, Post hoc tests (Tukey HSD) show no significant difference between these three rules for different cost coefficients levels, thus indicating that when the emergency cases show up, simple alternations of cases sequence would not significantly improve overall performance if the cost of idle time and overtime increase. The ANOVA results are provided in the Appendix B Table B 19 to Table B 21. The appearance of emergency cases increases patient waiting time and overtime largely but reduces surgeon idle time. However, the reduction of cost from idle time cannot offset the cost from both waiting time and overtime.

Figure 8

Scenario 2 Comparison of Sequencing Rules (c_{it}, c_o= 5, 10, 15)



4.1.7 Case 1 Scenario 3 Shared ORs with Emergency Cases

The comparison of results for the sequencing rules in Scenario 3 is in Table 19. The line graph Figure 9 (c_{it}, c_o= 5, 10, 15) provides a more straightforward comparison of the rules. In Scenario 3, the SPT rule has the lowest total expected cost, while the LPT rule results in highest lowest expected total cost across three cost coefficients levels. In terms of the four alternated rules, the expected total costs in AR 2 and AR 4 are lower than those in AR 1 and AR 3, but none of them is lower than the results in SPT rule.

Table 19

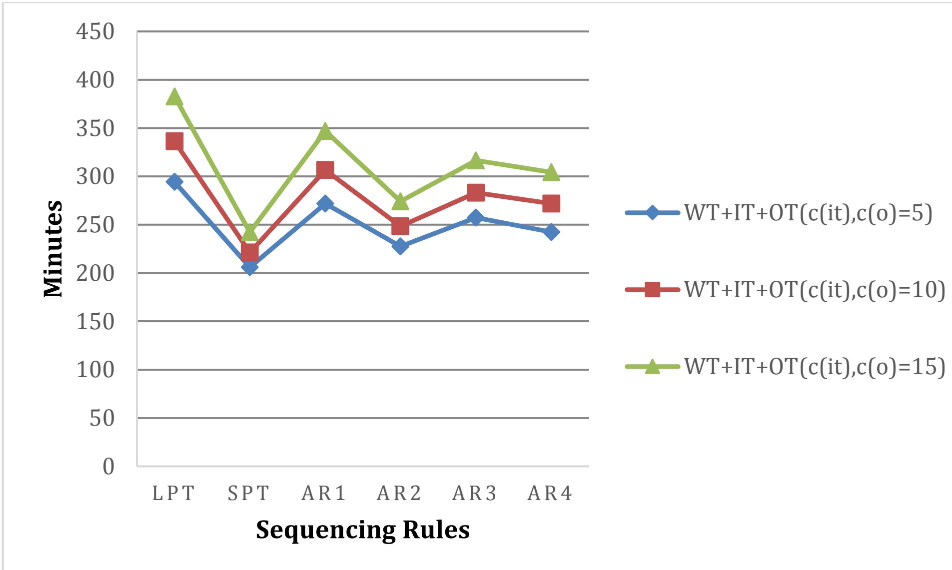
Scenario 3, Comparison of Sequencing Rules (c_{it}, c_o= 5, 10, 15)

	LPT	SPT	AR1	AR2	AR3	AR4
Performance Measure	**Average, 95% C.I.**					
c_{it}, c_o= 5						
Total Waiting Time (min)	220.72 ± 14.92	123.83 ± 12.3	197.03 ± 13.85	147.76 ± 12.84	178.08 ± 13.12	166.97 ± 13.63
Total Idle Time (min)	4.74 ± 1.01	10.18 ± 1.23	5.65 ± 1.15	8.65 ± 1.16	8.36 ± 1.14	6.07 ± 1.17
Overtime (min)	68.73 ± 8.37	71.97 ± 8.36	69.09 ± 8.37	71.10 ± 8.41	70.84 ± 8.42	69.38 ± 8.37
Utilization	1.00 ± 0	1.00 ± 0	1.00 ± 0	1.00 ± 0	1.00 ± 0	1.00 ± 0
WT5IT5OT	588.07 ± 52.06	534.55 ± 49.08	570.70 ± 51.25	546.48 ± 50.13	574.06 ± 51.01	544.24 ± 50.37
c_{it}, c_o= 10						
Total Waiting Time (min)	266.33 ± 14.98	145.66 ± 12.16	235.81 ±14.08	174.22 ± 12.87	209.20 ± 12.98	201.01 ± 13.86
Total Idle Time (min)	2.17 ± 0.64	5.83 ± 0.88	2.79 ± 0.74	4.86 ± 0.8	4.72 ± 0.79	2.91 ± 0.75
Overtime (min)	67.73 ± 8.34	69.73 ± 8.34	67.94 ± 8.34	69.19 ± 8.37	69.10 ± 8.37	68.02 ± 8.34
Utilization	1.00 ± 0	1.00 ± 0	1.00 ± 0	1.00 ± 0	1.00 ± 0	1.00 ± 0
WT10IT10OT	965.24 ±93.12	901.19 ± 90.1	943.09 ± 92.34	914.64 ± 91.23	947.36 ± 92	910.32 ± 91.57
c_{it}, c_o= 15						
Total Waiting Time (min)	314.46 ± 15.09	170.66 ± 12.06	278.48 ± 14.07	203.48 ± 12.65	245.78 ± 13.07	235.78 ± 13.54
Total Idle Time (min)	0.96 ± 0.37	3.11 ± 0.6	1.20 ± 0.43	2.60 ± 0.53	2.59 ± 0.54	1.22 ± 0.42
Overtime (min)	67.26 ± 8.33	68.43 ± 8.33	67.35 ± 8.33	68.16 ± 8.34	68.15 ± 8.34	67.38 ± 8.33
Utilization	1.00 ± 0	1.00 ± 0	1.00 ± 0	1.00 ± 0	1.00 ± 0	1.00 ± 0
WT15IT15OT	1337.74 ±134.37	1243.63 ±131.78	1306.65 ±133.69	1264.90 ±132.01	1306.94 ±133.39	1264.74 ±132.29

In a comparison of these six sequencing rules, the difference in performance is not statistically significant between these rules in terms of three levels of cost coefficients, thus it can be said that changing sequencing rules in scenarios 3 would not make a significant improvement in performance after adding 10% arrival rates of emergency cases. The results can be seen in the Appendix B Table B 22 to Table B 24.

Figure 9

Scenario 3 Comparison of Sequencing Rules (c_{it}, c_o= 5, 10, 15)



4.1.8 Case 1 Comparison of Three Scenarios with Emergency Cases

The expected total costs of scenarios are given in Table 20 for cost coefficients levels of five, ten and 15. In the comparison of three scenarios in three different cases, Scenario 2, “Partially Shared ORs”, results in the lowest expected total cost with 2974.68 when c_{it}, c_o= 5, 3538.95 when c_{it}, c_o= 10, and 6848.04 when c_{it}, c_o= 15. This finding is consistent with that in Section 4.1.4.

Table 20

Expected total cost for Case 1 (c_{it}, c_o= 5, 10, 15)

		Short Procedures (80 Minutes)	Long Procedures (160 Minutes)	Total OR Time	Expected Total Cost $c_{it}, c_o = 5$	Expected Total Cost $c_{it}, c_o = 10$	Expected Total Cost $c_{it}, c_o = 15$
Scenario 1	OR 1 - 2	6		480 * 2	757.83 * 2	1225.39 * 2	1671.8* 2
	OR 3 - 6		3	480 * 4	418.86 * 4	707.82 * 4	993.24* 4
	Total			**2880**	**3191.1**	**5283.06**	**7316.56**
Scenario 2	OR 1 - 3	4	1	480 * 3	572.70 * 3	943.71 * 3	1289.44* 3
	OR 4 - 6		3	480 * 3	418.86 * 3	707.82 * 3	993.24 * 3
	Total			**2880**	**2974.68**	**3538.95**	**6848.04**
Scenario 3	OR 1 - 6	2	2	480 * 6	534.55 * 6	901.19 * 6	1243.63 * 6
	Total			**2880**	**3207.3**	**5407.14**	**7461.78**

4.1.9 Key Insights from Case 1

Table 21 provides a summary of the results for Case 1. The relevant appointment and sequencing rules for each case are specified. In Scenario 1, the VI rules produced the lowest expected total cost. Based on the ANOVA results, the improvement in overall performance is not significant among these rules when the probability of emergency cases is 0% or 10%. Therefore, the fixed interval rules and the variable interval rules are not significantly different in terms of performance from the perspective of expected total cost. In Scenario 2 and Scenario 3, where different procedure types can be scheduled in the same OR, the results showed the choice of sequencing rule to be statistically significant. The SPT rule results in lower expected total cost, but the improvement is statistically significant only when c_{it}, c_o= 5 and with no emergency cases. Scenario 2, "Partially Shared ORs", where some of the ORs are occupied by one procedure type and some are allocated multiple procedure types, results in the lowest expected total cost, thus, it is the best allocation rule for Case 1.

Table 21

Summary of Results in Case 1

Factors					Results				
					0% Emergency Cases		10% Emergency Cases		
Scenarios	**ORs Allocations**	**Appointment Rules**	**Sequencing Rules**	**Cost Coefficients for Idle Time, Overtime**	**Appointment Rules**	**Sequencing Rules**	**Appointment Rules**	**Sequencing Rules**	**Expected Total Cost**
Scenario 1: Dedicated ORs	OR 1 - 2: 6 SP only	FI, VI	N/A	5	VI	N/A	VI	N/A	
				10	VI	N/A	VI	N/A	
				15	VI	N/A	VI	N/A	
	OR 3 - 6: 3 LP only	FI, VI	N/A	5	VI	N/A	FI	N/A	
				10	VI	N/A	VI	N/A	
				15	VI	N/A	VI	N/A	
Scenario 2: Partially Shared ORs	OR 1 - 3: 4 SP + 1 LP	FI	LPT, SPT, AR 3	5	FI	SPT*	FI	SPT	Lowest
				10	FI	SPT	FI	SPT	
				15	FI	SPT	FI	SPT	
	OR 4 - 6: 3 LP only	FI, VI	N/A	5	VI	N/A	FI	N/A	
				10	VI	N/A	VI	N/A	
				15	VI	N/A	VI	N/A	
Scenario 3: Shared ORs	OR 1 - 6: 2 SP + 2 LP	FI	LPT, SPT, AR 1 – AR 4	5	FI	SPT*	FI	SPT	Highest
				10	FI	SPT	FI	SPT	
				15	FI	SPT	FI	SPT	

* The mean difference is significant at the 0.05 level.
SP ~ Short Procedure, Lognormal (80, 20)
LP ~ Long Procedure, Lognormal (160, 40)

4.2 Case 2: Two Procedure Types Using CIHI Data

In Case 2, the data from CIHI are used, and two procedure types within three scenarios and six ORs are tested. Appointment rules and allocation rules are different from Case 1. Sequencing rules are the same. The probability of emergency cases is 0%, 10%. The fixed interval rules in Table 3 and each set of variable interval rules based on surgery mean durations in Table 22 and Table 23 are tested to determine best rules. Detailed factors and rules are shown in Table 24.

Table 22

Variable Interval (VI) Rule used for Short Procedures in Case 2

Interval #	Dome Rule	Interval #	Increasing Interval Rule
VI 1	43, 48, 53, 58, 63, 58, 53, 48	VI 4	33, 38, 43, 48, 53, 58, 63, 68
VI 2	38, 43, 48, 53, 58, 53, 48, 43	VI 5	28, 33, 38, 43, 48, 53, 58, 63
VI 3	33, 38, 43, 48, 53, 48, 43, 38	VI 6	23, 28, 33, 38, 43, 48, 53, 58

Table 23

Variable Interval Rule (VI) For Long Procedures in Case 2

Interval #	Increasing Interval Rule
VI 7	123, 133
VI 8	113, 123
VI 9	103, 113
VI 10	93, 103
VI 11	83, 93
VI 12	73, 83

The completed simulation results for all FI and VI rules can be seen in Appendix C Table C 1– Table C 2 for 0% emergency rate and Table C 3 – Table C 4 for 10% emergency rate. The ANOVA and t test results are provided in Appendix D (Table D 1– Table D 12) for 0% emergency rate and Table D 13 – Table D 24 for 10% emergency rate. It should be noted that, for the Variable Interval Rule, pretesting showed that “Dome Rule” and “Increasing Interval Rule” perform better than “Reverse Dome Rule” and “Decrease Interval Rule”. Thus, only the Dome and Increasing Interval rules are analyzed in the rest of the study. To allow consistent comparison with the results in Case 1, cost coefficient values of five, ten and 15 are tested.

Table 24

Summary of factors and rules for Case 2

Distributions/Types	SP ~ 30 + Exponential (22.9) LP ~ 44 + 254*BETA (1.98, 2.62)
Probability of emergency cases	0%, 10%
Appointment rules	SP: FI 1 – FI 5 VI 1 – VI 6 LP: FI 1 – FI5 VI 7 –VI 12
Allocation rules Scenario 1: Dedicated ORs Scenario 2: Partially Shared ORs Scenario 3: Shared ORs	 OR 1 – 2: 9 SP only OR 3 – 6: 3 LP only OR 1 – 3: 6 SP + 1 LP OR 4 – 6: 3 LP only OR 1 – 6: 3 SP +2 LP
Sequencing rules Scenario 1: Dedicated ORs Scenario 2: Partially Shared ORs Scenario 3: Shared OR	 OR 1 - 6: No Sequencing Rules OR 1 – 3: LPT, SPT, AR3 OR 4 – 6: No Sequencing Rules OR 1 – 6: LPT, SPT, AR 1-4

*SP ~ Short Procedure
**LP ~ Long Procedure

4.2.1 Case 2 Scenario 1 Dedicated ORs with No Emergency Cases

The results for best fixed and variable interval rules for Short Procedures are given in Table 25. The Dome Rule (VI 2, VI 3, VI 3) has the lowest total expected cost compared to other rules when c_{it}, c_o= 5, 10 and 15 with 520.87 ± 38.13, 726.49 ± 59.61, 876.9 ± 77.23 respectively. As shown in Appendix D Table D 1 to Table D 3, in a comparison of FI rules and VI rules (i.e. Dome Rule and Increasing Interval Rule) across three different cost coefficients (i.e. five, ten and 15), all Post hoc test (Tukey HSD) results show that the difference in performance is not statistically significant, thus validating that the fixed interval rules and the variable interval rules are not significantly different in producing lower expected total cost for Short Procedures.

Table 25

Scenario 1, Comparison of Best Rule in FI and VI for Short Procedures (c_{it}, c_o= 5, 10, 15)

	Fixed Interval	**Dome Rule**	**Increasing Interval Rule**
Performance Measure	**Average, 95% C.I.**		
c_{it}, c_o= 5			
	FI 2	**VI 2**	**VI 4**
Total Waiting Time (min)	301.09 ± 24.28	298.68 ± 24.64	345.16 ± 26.22
Total Idle Time (min)	19.66 ± 1.74	16.47 ± 1.87	17.20 ± 2.24
Overtime (min)	30.54 ± 3.98	27.97 ± 3.84	26.29 ± 3.76
Utilization	0.96 ± 0	0.96 ± 0	0.96 ± 0
WT5IT5OT	552.09 ± 39.19	520.87 ± 38.13	562.59 ± 38.03
c_{it}, c_o= 10			
	FI 3	**VI 3**	**VI 4**
Total Waiting Time (min)	418.69 ± 27.07	425.69 ± 27.82	345.16 ± 26.22
Total Idle Time (min)	8.07 ± 0.92	4.66 ± 0.89	17.2 ± 2.24
Overtime (min)	27.39 ± 3.86	25.42 ± 3.76	26.29 ± 3.76
Utilization	0.98 ± 0	0.99 ± 0	0.96 ± 0
WT10IT10OT	773.29 ± 60.52	726.49 ± 59.61	780.02 ± 53.65
c_{it}, c_o= 15			
	FI 3	**VI 3**	**VI 5**
Total Waiting Time (min)	418.69 ± 27.07	425.69 ± 27.82	493.55 ± 28.67
Total Idle Time (min)	8.07 ± 0.92	4.66 ± 0.89	4.71 ± 1.03
Overtime (min)	27.39 ± 3.86	25.42 ± 3.76	24.87 ± 3.73
Utilization	0.98 ± 0	0.99 ± 0	0.99 ± 0
WT15IT15OT	950.59 ± 78.93	876.9 ± 77.23	937.27 ± 76.67

Table 26

Scenario 1, Comparison of Best Rule in FI and VI for Long Procedures (c_{it}, c_o= 5, 10, 15)

	Fixed Interval	**Increasing Interval**
Performance Measure	**Average, 95% C.I.**	
c_{it}, c_o= 5		
	FI 9	**VI 8**
Total Waiting Time (min)	132.94 ± 8.89	124.22 ± 8.76
Total Idle Time (min)	9.66 ± 1.69	10.94 ± 1.88
Overtime (min)	30.44 ± 4.41	30.49 ± 4.4
Utilization	0.98 ± 0	0.97 ± 0
WT5IT5OT	333.40 ± 27.28	331.37 ± 27.06
c_{it}, c_o= 10		
	FI 13	**VI 10**
Total Waiting Time (min)	182.69 ± 9.85	173.25 ± 9.77
Total Idle Time (min)	3.45 ± 0.83	4.02 ± 0.95
Overtime (min)	29.60 ± 4.39	29.60 ± 4.39
Utilization	0.99 ± 0	0.99 ± 0
WT10IT10OT	513.25 ± 49.72	509.46 ± 49.51
c_{it}, c_o= 15		
	FI 15	**VI 11**
Total Waiting Time (min)	209.57 ± 10.19	199.88 ± 10.14
Total Idle Time (min)	1.6164 ± 0.5	1.925 ± 0.58
Overtime (min)	29.45 ± 4.39	29.45 ± 4.39
Utilization	1.00 ± 0	0.99 ± 0
WT15IT15OT	675.51 ± 72.06	670.45 ± 71.87

The results for the best fixed and variable interval rules for Long Procedures can be seen in Table 26. Since only three Long Procedures are performed, the Dome Rule is not applicable since the number of procedures is too small. When c_{it}, c_o= 5, 10 and 15, the Increasing Interval Rule (VI

8, VI 10, VI 11) produces best results, with 331.37 ± 27.06, 509.46 ± 49.51 and 670.45 ± 71.87 respectively. In a comparison of FI rules and VI rules (i.e. Increasing Interval Rule) across three different cost coefficients (i.e. five, ten and 15), $\boldsymbol{t}$ test results indicate that the difference in performance is not statistically significant. Thus, both the fixed interval rules and the variable interval rules produce a lower expected total cost for Long Procedures. The results are in Appendix D Table D 4 to Table D 6.

4.2.2 Case 2 Scenario 2 Partially Shared ORs with No Emergency Cases

In Scenario 2, the LPT, SPT and AR 3 sequencing rules are tested. The AR 1, the AR 2 and the AR 4 rules are not applicable since there is only one Long Procedure in this scenario. In Scenario 1, the ANOVA and t test results showed that the fixed interval rule and the variable interval rule are not significantly different in getting a lower expected total cost. To keep the analysis of results brief, for the Scenario 2, the best FI rules from Scenario 1 are used.

A comparison of sequencing rules is given in Table 27. Figure 10 provides a more intuitive comparison. The SPT rule has the lowest expected total cost when c_{it}, c_o= 5, 10 and 15, with 458.53 ± 32.7, 657.93 ± 54.9 and 862.48 ± 75.62 respectively. Even though the SPT rule does not result in lowest idle time and overtime, it largely reduces waiting time.

In a comparison of these three sequencing rules, all Post hoc tests (Tukey HSD) reveal that the expected total cost is statistically significantly lower in the SPT rule compared to LPT rule and AR 3 across three cost coefficients levels, thus indicating that the SPT rule makes a significant improvement in overall performance. Results show that the difference in performance is not statistically significant between the LPT rule and AR 3. The results are shown in Appendix D Table D 7 to Table D 9.

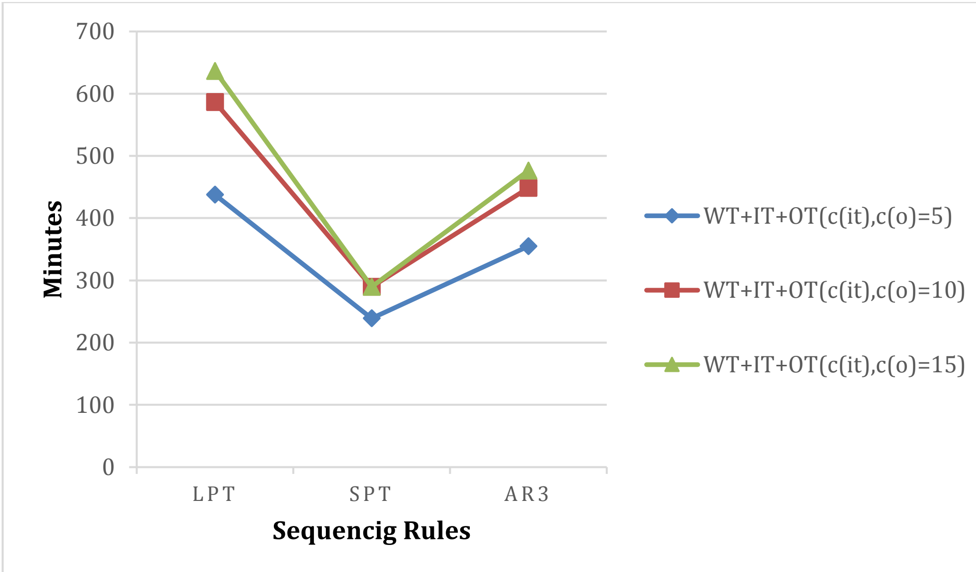
Table 27

Scenario 2, Comparison of Sequencing Rules (c_{it}, c_o= 5, 10, 15)

	LPT	SPT	AR3
Performance Measure	**Average, 95% C.I.**		
c_{it}, c_o= 5			
Total Waiting Time (min)	394.56 ± 26.57	184.13 ± 16.36	301.38 ± 19.95
Total Idle Time (min)	11.65 ± 1.87	17.49 ± 1.52	17.61 ± 1.7
Overtime (min)	31.35 ± 4.23	37.39 ± 4.44	35.88 ± 4.43
Utilization	0.97 ± 0	0.96 ± 0	0.96 ± 0
WT5IT5OT	609.59 ± 41.25	458.54 ± 32.7	568.84 ± 37.5
c_{it}, c_o= 10			
Total Waiting Time (min)	552.18 ± 30.19	248.83 ± 18.11	408.56 ± 22.06
Total Idle Time (min)	3.61 ± 0.86	7.71 ± 0.87	7.38 ± 0.85
Overtime (min)	30.51 ± 4.22	33.20 ± 4.32	32.91 ± 4.32
Utilization	0.99 ± 0	0.98 ± 0	0.98 ± 0
WT10IT10OT	893.36 ± 65.3	657.93 ± 54.9	811.49 ± 60.36
c_{it}, c_o= 15			
Total Waiting Time (min)	604.19 ± 31.08	248.83 ± 18.11	436.92 ± 22.26
Total Idle Time (min)	2.08 ± 0.6	7.71 ± 0.87	6.79 ± 0.77
Overtime (min)	30.41 ± 4.22	33.20 ± 4.32	32.90 ± 4.32
Utilization	0.99 ± 0	0.98 ± 0	0.98 ± 0
WT15IT15OT	1091.50 ± 86.69	862.48 ± 75.62	1032.28 ± 81.75

Figure 10

Scenario 2 Comparison of Sequencing Rules (c_{it}, c_o= 5, 10, 15)



4.2.3 Case 2 Scenario 3 Shared ORs with No Emergency Cases

In Scenario 3, (1) LPT rule, (2) SPT rule, (3) AR 1, (4) AR 2, (5) AR 3 and (6) AR 4 are tested in this scenario. Similar to Scenario 2, the best FI rules from Scenario 1 are used. In a comparison of these six rules, the SPT rule (372.76 ± 27.8, 544.35 ± 49.32, 735.20 ± 70.44) performs the best in overall performance while the LPT rule (523.35 ± 36.56, 776.72 ± 59.33, 971.94 ± 80.97) has the highest expected total cost across three cost coefficients levels. The expected total costs in the four alternated rules are in between, and they show decrease trends from AR 1 to AR 4. The comparisons can be seen in Table 28 and Figure 11.

When c_{it}, c_o= 5 and 10, Post hoc test (Tukey HSD) results show that there is a statistically significant difference between the SPT rule and the LPT rule, AR 1 and AR 2, thus indicating that the SPT rule has significant improvement in getting lower expected total cost compared to these three rules. When c_{it}, c_o= 15, the significant difference is still between the SPT rule and the LPT rule or AR 1, but not between the SPT rule and AR 2. Therefore, in terms of overall performance, it is better to avoid the LPT rule but use the SPT rule in this scenario. The comparison ANOVA results are shown in Appendix D Table D 10 to Table D 12.

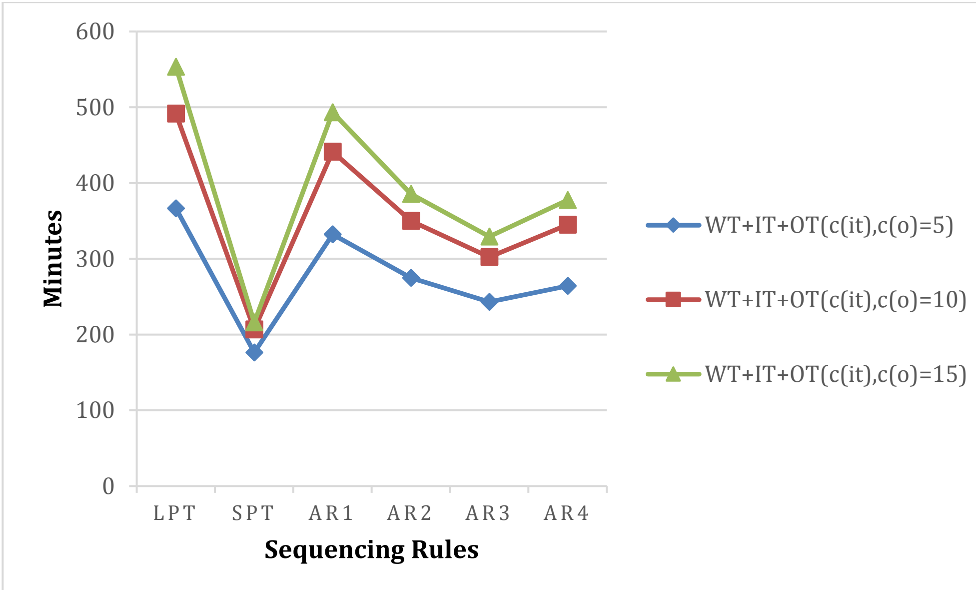
Table 28

Scenario 3, Comparison of Sequencing Rules (c_{it}, c_o= 5, 10, 15)

	LPT	SPT	AR1	AR2	AR3	AR4
Performance Measure	**Average, 95% C.I.**					
c_{it}, c_o= 5						
Total Waiting Time (min)	327.40 ± 20.73	127.16 ± 10.12	292.10 ± 18.73	228.78 ± 14.93	194.45 ± 12.47	224.35 ± 16.7
Total Idle Time (min)	10.16 ± 1.77	16.06 ± 1.49	10.88 ± 1.8	14.58 ± 1.71	16.27 ± 1.67	10.48 ± 1.72
Overtime (min)	29.03 ± 4.19	33.07 ± 4.42	29.09 ± 4.2	31.20 ± 4.34	32.32 ± 4.39	29.20 ± 4.2
Utilization	0.975 ± 0	0.964 ± 0	0.973 ± 0	0.966 ± 0	0.962 ± 0	0.975 ± 0
WT5IT5OT	523.35 ± 36.56	372.76 ± 27.8	491.94 ± 34.59	457.69 ± 32.13	437.39 ± 30.49	422.74 ± 31.7
c_{it}, c_o= 10						
Total Waiting Time (min)	459.71 ± 22.94	169.24 ± 11.12	409.19 ± 20.9	314.34 ± 16.51	264.91 ± 13.72	312.64 ± 18.77
Total Idle Time (min)	3.22 ± 0.78	7.04 ± 0.81	3.48 ± 0.81	5.88 ± 0.79	6.90 ± 0.82	3.59 ± 0.84
Overtime (min)	28.48 ± 4.2	30.47 ± 4.3	28.52 ± 4.2	29.76 ± 4.27	30.23 ± 4.29	28.52 ± 4.2
Utilization	0.99 ± 0	0.98 ± 0	0.99 ± 0	0.99 ± 0	0.98 ± 0	0.99 ± 0
WT10IT10OT	776.72 ± 59.33	544.35 ± 49.32	729.20 ± 57.38	670.76 ± 54.5	636.22 ± 52.46	633.72 ± 54.16
c_{it}, c_o= 15						
Total Waiting Time (min)	523.40 ± 23.67	178.82 ± 11.17	463.13 ± 21.57	351.20 ± 16.89	293.26 ± 13.92	347.01 ± 19.38
Total Idle Time (min)	1.45 ± 0.44	6.62 ± 0.74	1.70 ± 0.51	4.59 ± 0.59	5.95 ± 0.67	2.02 ± 0.59
Overtime (min)	28.45 ± 4.2	30.47 ± 4.3	28.45 ± 4.2	29.76 ± 4.27	30.23 ± 4.29	28.45 ± 4.2
Utilization	1.00 ± 0	0.98 ± 0	1.00 ± 0	0.99 ± 0	0.99 ± 0	0.99 ± 0
WT15IT15OT	971.94 ± 80.97	735.20 ± 70.44	915.46 ± 78.93	866.46 ± 76.18	835.89 ± 73.95	804.17 ± 75.41

Figure 11

Scenario 3 Comparison of Sequencing Rules (c_{it}, c_o= 5, 10, 15)



4.2.4 Case 2 Comparison of Three Scenarios with No Emergency Cases

The expected total costs for each scenario for all six ORs are shown in Table 29 for cost coefficients levels of five, ten and 15 respectively. In the comparison of three scenarios in three different cases, Scenario 3, "Shared ORs", results in the lowest expected total cost with 2236.56 when c_{it}, c_o= 5, 3266.1 when c_{it}, c_o= 10, and 4411.2 when c_{it}, c_o= 15. Thus, an allocation rule that uses all ORs to multiple surgery types may improve performance compared to other allocation rules in Case 2.

Table 29

Expected total cost for Case 2 (c_{it}, c_o= 5, 10, 15)

		Short Procedures (52.9 Minutes)	Long Procedures (153 Minutes)	Total OR Time	Expected Total Cost $c_{it}, c_o = 5$	Expected Total Cost $c_{it}, c_o = 10$	Expected Total Cost $c_{it}, c_o = 15$
Scenario 1	OR 1 - 2	9		477 * 2	552.09 * 2	773.29 * 2	950.59* 2
	OR 3 - 6		3	459 * 4	333.40 * 4	513.25 * 4	675.51* 4
	Total			**2790**	**2437.78**	**3599.58**	**4603.22**
Scenario 2	OR 1 - 3	6	1	471 * 3	458.54 * 3	657.93 * 3	862.48* 3
	OR 4 - 6		3	459 * 3	333.40 * 3	513.25 * 3	675.51* 3
	Total			**2790**	**2375.82**	**3513.54**	**4613.97**
Scenario 3	OR 1 - 6	3	2	465 * 6	372.76 * 6	544.35 * 6	735.20* 6
	Total			**2790**	**2236.56**	**3266.1**	**4411.2**

4.2.5 Case 2 Scenario 1 Dedicated ORs with Emergency Cases

The probability of emergency arrivals is set at 10% emergency rate. The results for best fixed and variable interval rules for Short Procedures are given in Table 30. The Dome Rule (VI 2, VI 3, VI 3) has the lowest total expected cost compared to other rules when c_{it}, c_o= 5, 10 and 15 with 1170.51 ± 95.36, 1757.4 ± 149.11, 2299.25 ± 205.64 respectively. In a comparison of FI rules and VI rules (i.e. Dome Rule and Increasing Interval Rule) across three different cost coefficients (i.e. five, ten and 15), all Post hoc test (Tukey HSD) results show that the difference in performance is not statistically significant, thus indicating that the fixed interval rules and the variable interval rules are not significantly different in resulting lower expected total cost for Short Procedures. The results are shown in Appendix D Table D 13 to Table D 15.

The results for the best fixed and variable interval rules for Long Procedures are in Table 31. When c_{it}, c_o= 5, 10 and 15, the Increasing Interval Rule (VI 8, VI 10, VI 11) produces best results, with 460.90 ± 43.1, 756.28 ± 79.67 and 1033.58 ± 115.99 respectively. In a comparison of FI rules and VI rules (i.e. Increasing Interval Rule) across three different cost coefficients (i.e. five, ten and 15), t test results show that the difference in performance is not statistically significant, thus validating that there is no significantly different between the fixed interval rules and the variable interval rules in producing a lower expected total cost for Long Procedures. The results are in Appendix D Table D 16 to Table D 18.

Table 30

Scenario 1, Comparison of Best Rule in FI and VI for Short Procedures (c_{it}, c_o= 5, 10, 15)

	Fixed Interval	Dome	Increasing Interval
Performance Measure	**Average, 95% C.I.**		
c_{it}, c_o= 5			
	FI 2	**VI 2**	**VI 4**
Total Waiting Time (min)	580.94 ± 47.3	583.61 ± 47.82	624.12 ± 47.39
Total Idle Time (min)	14.06 ± 1.46	10.24 ± 1.51	8.91 ± 1.65
Overtime (min)	109.53 ± 11.48	107.14 ± 11.5	105.06 ± 11.42
Utilization	1.00 ± 0	1.00 ± 0	1.00 ± 0
WT5IT5OT	1198.88 ± 94.91	1170.51 ± 95.36	1193.94 ± 93.74
c_{it}, c_o= 10			
	FI 3	**VI 2**	**VI 4**
Total Waiting Time (min)	688.04 ± 48.08	583.61 ± 47.82	624.12 ± 47.39
Total Idle Time (min)	6.08 ± 0.77	10.24 ± 1.51	8.91 ± 1.65
Overtime (min)	106.69 ± 11.5	107.14 ± 11.5	105.06 ± 11.42
Utilization	1.00 ± 0	1.00 ± 0	1.00 ± 0
WT10IT10OT	1815.71 ± 150.42	1757.4 ± 149.11	1763.76 ± 146.38
c_{it}, c_o= 15			
	FI 3	**VI 3**	**VI 4**
Total Waiting Time (min)	688.04 ± 48.08	698 ± 48.22	624.12 ± 47.39
Total Idle Time (min)	6.08 ± 0.77	2.63 ± 0.67	8.91 ± 1.65
Overtime (min)	106.69 ± 11.5	104.12 ± 11.43	105.06 ± 11.42
Utilization	1.00 ± 0	1.00 ± 0	1.00 ± 0
WT15IT15OT	2379.54 ± 206.34	2299.25 ± 205.64	2333.59 ± 200.41

Table 31

Scenario 1, Comparison of Best Rule in FI and VI for Long Procedures (c_{it}, c_o= 5, 10, 15)

	Fixed Interval	**Increasing Interval**
Performance Measure	**Average, 95% C.I.**	
c_{it}, c_o= 5		
	FI 9	**VI 8**
Total Waiting Time (min)	149.29 ± 10.32	140.77 ± 10.29
Total Idle Time (min)	8.20 ± 1.56	9.19 ± 1.72
Overtime (min)	54.71 ± 7.43	54.84 ± 7.42
Utilization	1.00 ± 0	1.00 ± 0
WT5IT5OT	463.85 ± 43.21	460.90 ± 43.1
c_{it}, c_o= 10		
	FI 13	**VI 10**
Total Waiting Time (min)	195.37 ± 10.67	187.02 ± 10.68
Total Idle Time (min)	2.94 ± .78	3.34 ± 0.88
Overtime (min)	53.54 ± 7.38	53.58 ± 7.38
Utilization	1.00 ± 0	1.00 ± 0
WT10IT10OT	760.18 ± 79.70	756.28 ± 79.67
c_{it}, c_o= 15		
	FI 15	**VI 11**
Total Waiting Time (min)	219.11 ± 10.58	210.61 ± 10.45
Total Idle Time (min)	1.42 ± 0.47	1.63 ± 0.55
Overtime (min)	53.21 ± 7.37	53.23 ± 7.37
Utilization	1.00 ± 0	1.00 ± 0
WT15IT15OT	1038.67 ± 116.12	1033.58 ± 115.99

4.2.6 Case 2 Scenario 2 Partially Shared ORs with Emergency Cases

In a comparison of the LPT rule, the SPT rule and the AR 3, the SPT rule results in lowest expected total cost. The results are shown in Table 32. The line graph is in Figure 12. When c_{it}, c_o= 5, the lowest expected total cost is 901.19 ± 75.03 and the lowest patient waiting time is 337.86 ± 31.36 minutes, with the SPT rule. The LPT rule results in lowest idle time (9.46 ± 1.7) and overtime (95.0 ± 10.72 minutes). Due to the highest waiting time (515.01 ± 32.35 minutes), the LPT rule has the highest expected total cost (1037.16 ± 75.44). When the cost coefficient increases to ten and 15, the SPT rule still results in lowest expected total cost compared to other rules.

When c_{it}, c_o= 5, Post hoc test (Tukey HSD) reveals that the expected total cost is statistically significantly lower in the SPT rule (901.19 ± 75.03, $p = 0.033$) compared to the LPT rule (1037.16 ± 75.44), thus indicating that the SPT rule makes a significant improvement in overall performance compared to the LPT rule. When c_{it}, c_o= 10 and 15, the difference in performance is not statistically significant between these three rules, thus indicating that when the emergency cases show up, simple alternating of long and short cases would not have a significant improvement in the overall performance if the cost coefficients of idle time and overtime increase. Even though the appearance of emergency cases reduces surgeon idle time, as expected, they increase patient waiting time and overtime. The reduction of idle time cost cannot compensate for the increase in waiting time and overtime costs. The ANOVA results are provided in the Appendix D Table D 19 to Table D 21.

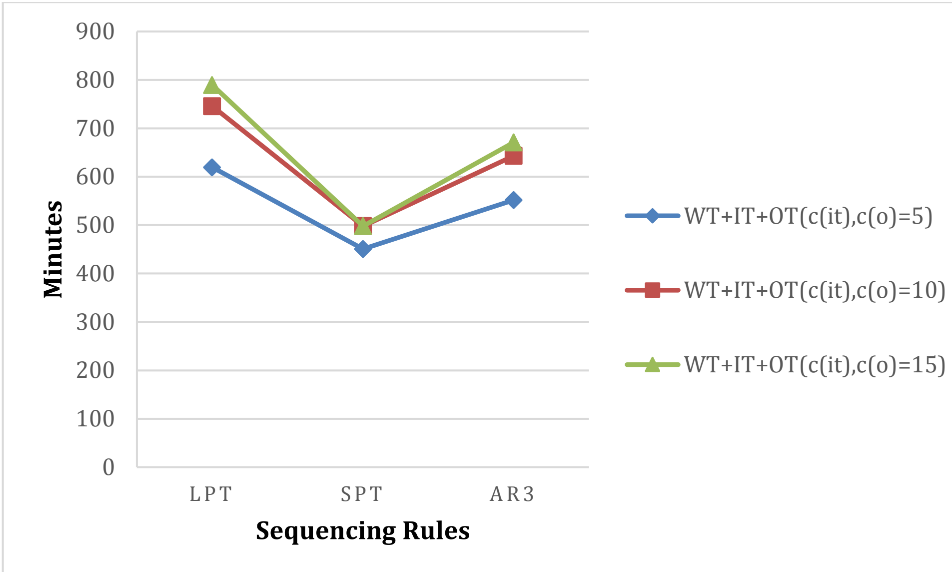
Table 32

Scenario 2, Comparison of Sequencing Rules (c_{it}, c_o= 5, 10, 15)

	LPT	SPT	AR3
Performance Measure	**Average, 95% C.I.**		
c_{it}, c_o= 5			
Total Waiting Time (min)	515.01 ± 32.36	337.86 ± 31.36	439.85 ± 32.45
Total Idle Time (min)	9.46 ± 1.7	13.69 ± 1.41	14.07 ± 1.59
Overtime (min)	95.0 ± 10.72	99.0 ± 10.67	97.9 ± 10.69
Utilization	1.00 ± 0	1.00 ± 0	1.00 ± 0
WT5IT5OT	1037.16 ± 75.44	901.19 ± 75.03	999.90 ± 75.96
c_{it}, c_o= 10			
Total Waiting Time (min)	649.92 ± 33.43	395.95 ± 31.33	541.29 ± 32.98
Total Idle Time (min)	2.99 ± 0.79	6.23 ± 0.8	6.15 ± 0.8
Overtime (min)	92.88 ± 10.67	95.64 ± 10.73	95.38 ± 10.74
Utilization	1.00 ± 0	1.00 ± 0	1.00 ± 0
WT10IT10OT	1608.64 ±126.75	1414.58 ± 126.99	1556.58 ± 128.5
c_{it}, c_o= 15			
Total Waiting Time (min)	695.13 ± 33.23	395.95 ± 31.33	569.51 ± 33.09
Total Idle Time (min)	1.75 ± 0.56	6.23 ± 0.8	5.72 ± 0.72
Overtime (min)	92.61 ± 10.67	95.64 ± 10.73	95.37 ± 10.74
Utilization	1.00 ± 0	1.00 ± 0	1.00 ± 0
WT15IT15OT	2110.42 ± 179	1923.90 ± 179.4	2085.83 ±181.41

Figure 12

Scenario 2 Comparison of Sequencing Rules (c_{it}, c_o= 5, 10, 15)



4.2.7 Case 2 Scenario 3 Shared ORs with Emergency Cases

In Scenario 3, the SPT rule is the best rule in getting the lowest total expected cost, while the LPT rule results in highest lowest expected total cost across three cost coefficients levels. In terms of the four alternated rules, the expected total costs are in between, and they show decrease trends from AR 1 to AR 4. Detailed results are given in Table 33. The line graph of the comparison is in Figure 13.

In a comparison of these rules, when c_{it}, c_o= 5, Post hoc test (Tukey HSD) show that the expected total cost is statistically significantly lower in the SPT rule (616.27 ± 56.93, $p = 0.015$) compared to the LPT rule (751.55 ± 59.5), thus indicating that the SPT rule makes a significant improvement in overall performance compared to the LPT rule. When c_{it}, c_o= 10 and 15, there is no significant difference between these six rules, thus it can be said that changing sequencing rules in scenarios 3 would not make a significant improvement in performance. The results can be seen in the Appendix D Table D 22 to Table D 24.

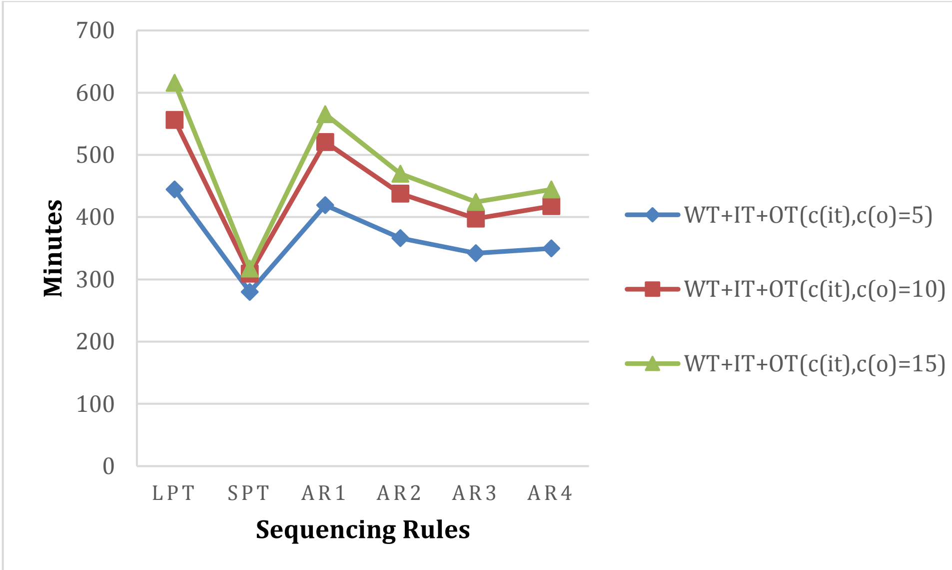
Table 33

Scenario 3, Comparison of Sequencing Rules (c_{it}, c_o= 5, 10, 15)

	LPT	SPT	AR1	AR2	AR3	AR4
Performance Measure	**Average, 95% C.I.**					
			c_{it}, c_o= 5			
Total Waiting Time (min)	367.63 ±23.49	195.92 ± 19.15	342.20 ± 22.45	284.14 ± 20.99	257.67 ± 20.07	273.18 ± 19.87
Total Idle Time (min)	8.80 ± 1.62	12.69 ± 1.31	9.27 ± 1.66	12.00 ± 1.55	13.36 ± 1.53	8.75 ± 1.52
Overtime (min)	67.98 ± 8.81	71.39 ± 8.91	67.99 ± 8.8	69.93 ± 8.88	70.94 ± 8.89	68.04 ± 8.8
Utilization	1.00 ± 0	1.00 ± 0	1.00 ± 0	1.00 ± 0	1.00 ± 0	1.00 ± 0
WT5IT5OT	751.55 ± 59.5	616.27 ± 56.93	728.49 ± 58.86	693.81 ± 58.61	679.16 ± 57.98	657.11 ± 56.43
			c_{it}, c_o= 10			
Total Waiting Time (min)	487.11 ± 25.24	234.70 ± 18.84	450.99 ± 23.34	364.98 ± 21.47	323.73 ± 20.2	348.32 ± 20.35
Total Idle Time (min)	2.73 ± 0.7	5.76 ± 0.72	2.94 ± 0.75	4.88 ± 0.72	5.76 ± 0.74	2.85 ± 0.73
Overtime (min)	66.56 ± 8.77	68.60 ± 8.84	66.57 ± 8.77	67.84 ± 8.82	68.33 ± 8.83	66.59 ± 8.77
Utilization	1.00 ± 0	1.00 ± 0	1.00 ± 0	1.00 ± 0	1.00 ± 0	1.00 ± 0
WT10IT10OT	1180.04 ±103.12	978.33 ±99.98	1146.07 ± 102.4	1092.24 ±102.22	1064.64 ± 101.49	1042.72 ± 99.37
			c_{it}, c_o= 15			
Total Waiting Time (min)	548.52 ± 25.69	243.21 ± 18.83	497.92 ± 23.2	398.23 ± 21.4	350.92 ± 20.31	376.71 ± 20.51
Total Idle Time (min)	1.19 ± 0.41	5.53 ± 0.68	1.40 ± 0.47	3.93 ± 0.54	5.11 ± 0.63	1.52 ± 0.5
Overtime (min)	66.30 ± 8.76	68.60 ± 8.84	66.31 ± 8.76	67.79 ± 8.82	68.32 ± 8.83	66.33 ± 8.76
Utilization	1.00 ± 0	1.00 ± 0	1.00 ± 0	1.00 ± 0	1.00 ± 0	1.00 ± 0
WT15IT15OT	1560.92 ±146.86	1355.08 ±143.49	1513.56 ±145.67	1474.10 ±145.87	1452.37 ± 145.34	1394.48 ±142.71

Figure 13

Scenario 3 Comparison of Sequencing Rules (c_{it}, c_o= 5, 10, 15)



4.2.8 Case 2 Comparison of Three Scenarios with Emergency Cases

The expected total costs for each scenario for all six ORs are given in Table 34 for cost coefficients levels of five, ten and 15 respectively. In the comparison of three scenarios in three different cases, Scenario 3, “Shared ORs”, always has the lowest expected total cost with 3697.62 when c_{it}, c_o= 5, 5869.98 when c_{it}, c_o= 10, and 8130.48 when c_{it}, c_o= 15. Therefore, it can be said that an allocation rule that assigns all ORs multiple surgery types may improve performance compared to other allocation rules in Case 2.

Table 34

Expected total cost for Case 2 (c_{it}, c_o= 5, 10, 15)

		Short Procedures (52.9 Minutes)	Long Procedures (153 Minutes)	Total OR Time	Expected Total Cost $c_{it}, c_o = 5$	Expected Total Cost $c_{it}, c_o = 10$	Expected Total Cost $c_{it}, c_o = 15$
Scenario 1	OR 1 - 2	9		477 * 2	1198.88 * 2	1815.71 * 2	2379.54 * 2
	OR 3 - 6		3	459 * 4	463.85* 4	760.18* 4	1038.67 * 4
	Total			**2790**	**4253.16**	**6672.14**	**8913.76**
Scenario 2	OR 1 - 3	6	1	471 * 3	901.19* 3	1414.58 * 3	1923.90 * 3
	OR 4 - 6		3	459 * 3	463.85 * 3	760.18 * 3	1038.67 * 3
	Total			**2790**	**4095.12**	**6524.28**	**8887.71**
Scenario 3	OR 1 - 6	3	2	465 * 6	616.27* 6	978.33 * 6	1355.08 * 6
	Total			**2790**	**3697.62**	**5869.98**	**8130.48**

4.2.9 Key Insights from Case 2

Table 35 provides a summary of the results tested in Case 2 that uses the data from CIHI and performs two procedure types. The results are similar to those in Case 1. The VI rules result in lower expected total cost, but the improvement in performance is not statistically significant in Scenario 1. Thus, the fixed interval rules and the variable interval rules are not significantly different in producing lower expected total cost. In Scenario 2 and Scenario 3, the SPT rule significantly reduces the expected total cost compared to other rules across three levels of cost coefficients with no emergency cases. When there is 10% emergency cases, the SPT rule makes improvement only when c_{it}, c_o = 5. Scenario 3, "Shared ORs", where all ORs are allocated different procedure types, always has the lowest expected total cost, therefore, it is the ideal allocation rule for Case 2.

Table 35

Summary of Results in Case 2

Factors					Results				
					0% Emergency Cases		10% Emergency Cases		
Scenarios	**ORs Allocations**	**Appointment Rules**	**Sequencing Rules**	**Cost Coefficients for Idle Time, Overtime**	**Appointment Rules**	**Sequencing Rules**	**Appointment Rules**	**Sequencing Rules**	**Expected Total Cost**
Scenario 1: Dedicated ORs	OR 1 - 2: 9 SP only	FI, VI	N/A	5	VI	N/A	VI	N/A	Highest
				10	VI	N/A	VI	N/A	
				15	VI	N/A	VI	N/A	
	OR 3 - 6: 3 LP only	FI, VI	N/A	5	VI	N/A	VI	N/A	
				10	VI	N/A	VI	N/A	
				15	VI	N/A	VI	N/A	
Scenario 2: Partially Shared ORs	OR 1 - 3: 6 SP + 1 LP	FI	LPT, SPT, AR 3	5	FI	SPT*	FI	SPT*	
				10	FI	SPT*	FI	SPT	
				15	FI	SPT*	FI	SPT	
	OR 4 - 6: 3 LP only	FI, VI	N/A	5	VI	N/A	VI	N/A	
				10	VI	N/A	VI	N/A	
				15	VI	N/A	VI	N/A	
Scenario 3: Shared ORs	OR 1 - 6: 3 SP + 2 LP	FI	LPT, SPT, AR 1 – AR 4	5	FI	SPT*	FI	SPT*	Lowest
				10	FI	SPT*	FI	SPT	
				15	FI	SPT*	FI	SPT	

*. The mean difference is significant at the 0.05 level.
SP ~ Short Procedure, 30 + Exponential (22.9)
LP ~ Long Procedure, 44 + 254 * BETA (1.98, 2.62)

4.3 Case 3: Three Procedure Types Using CIHI Data

In Case 3, one more procedure type, Moderate Procedure, is incorporated. The number of ORs and session length remain the same to investigate the impact of an additional procedure type on the simulation results. The fixed interval rules in Table 3 and each set of variable interval rules based on Moderate Procedure mean durations in Table 36 are tested. The completed simulation results for all FI and VI rules can be seen in Appendix E, Table E 1 and Table E 2, for 0% and 10% respectively. The ANOVA results are provided in Appendix F Table F 1– Table F 9 and Table F 10 – Table F 18 for 0% and 10% respectively. Summary of factors and rules for Case 3 is in Table 37.

Table 36

Variable Interval (VI) Rule used for Moderate Procedures in Case 3

Interval #	Dome Rule	Interval #	Increasing Interval Rule
VI 13	76, 86, 76	VI 16	76, 86, 96
VI 14	66, 76, 66	VI 17	66, 76, 86
VI 15	56, 66, 56	VI 18	56, 66, 76

Table 37

Summary of factors and rules for Case 3

Distributions/Types	SP *~ 30 + Exponential (22.9) MP** ~ 47 + GAMMA (29.2, 2.03) LP ***~ 44 + 254*BETA (1.98, 2.62)
Probability of emergency cases	0%, 10%
Appointment rules	MP: FI 1 – FI 9 VI 13 – VI 18
Allocation rules Scenario 1: Dedicated ORs Scenario 2: Partially Shared ORs Scenario 3: Shared ORs	 OR 1 - 2: 9 SP only OR 3 – 4: 4 MP only OR 5 – 6: 3 LP only OR 1 – 2: 4 MP only OR 3: 3 LP only OR 4 – 6: 6 SP + 1 LP OR 1 – 3: 4 SP + 1 MP + 1 LP OR 4 – 6: 1 SP + 2 MP + 1 LP
Sequencing rules Scenario 1: Dedicated ORs Scenario 2: Partially Shared ORs Scenario 3: Shared ORs	 OR 1– 6: No Sequencing Rules OR 1 – 2: No Sequencing Rules OR 3: No Sequencing Rules OR 4 – 6: LPT, SPT, AR1-4 OR 1– 6: LPT, SPT, AR 1-4

*SP ~ Short Procedure
**MP ~ Long Procedure
***LP ~ Long Procedure

4.3.1 Case 3 Scenario 1 Dedicated ORs with No Emergency Cases

As shown in Table 8, some of the allocations are identical. OR 1 and OR 2 are allocated to Short Procedures, and OR 5 and OR 6 perform Long Procedures. Therefore, the results are the same as those in Section 4.2.1 for Case 2 Scenario 1. OR 3 and OR 4 are allocated to Moderate Procedures and the results are provided in this section.

Table 38

Scenario 1, Comparison of Best Rule in FI and VI for Moderate Procedures (c_{it}, c_o= 5, 10, 15)

	Fixed Interval	**Dome Rule**	**Increasing Interval Rule**
Performance Measure	**Average, 95% C.I.**		
c_{it}, c_o= 5			
	FI 5	**VI 13**	**VI 16**
Total Waiting Time (min)	143.34 ± 12.31	170.50 ± 13.01	152.69 ± 12.81
Total Idle Time (min)	11.93 ± 1.48	6.76 ± 1.05	8.95 ± 1.35
Overtime (min)	17.58 ± 3.87	16.95 ± 3.82	17.04 ± 3.82
Utilization	0.97 ± 0	0.98 ± 0	0.98 ± 0
WT5IT5OT	290.89 ± 27.73	289.02 ± 28.32	282.62 ± 27.88
c_{it}, c_o= 10			
	FI 7	**VI 14**	**VI 17**
Total Waiting Time (min)	187.17 ± 13.29	219.21 ± 13.8	199.86 ± 13.72
Total Idle Time (min)	4.99 ± 0.82	2.02 ± 0.48	2.67 ± 0.63
Overtime (min)	16.86 ± 3.81	16.51 ± 3.77	16.51 ± 3.77
Utilization	0.99 ± 0	0.99 ± 0	0.99 ± 0
WT10IT10OT	405.59 ± 46.9	404.53 ± 47.27	391.67 ± 47.04
c_{it}, c_o= 15			
	FI 9	**VI 14**	**VI 17**
Total Waiting Time (min)	237.91 ± 13.93	219.21 ± 13.8	199.86 ± 13.72
Total Idle Time (min)	1.35 ± 0.33	2.02 ± 0.48	2.67 ± 0.63
Overtime (min)	16.49 ± 3.77	16.51 ± 3.77	16.51 ± 3.77
Utilization	1.00 ± 0	0.99 ± 0	0.99 ± 0
WT15IT15OT	505.55 ± 65.98	497.19 ± 65.73	487.58 ± 65.49

The results for best fixed and variable interval rules for Moderate Procedures are given in Table 38. Increasing Interval Rule (VI 16, VI 17, VI 17) has the lowest total expected cost compared to other rules when c_{it}, c_o= 5, 10 and 15 with 282.62 ± 27.88, 391.67 ± 47.04, 487.58 ± 65.49 respectively. In a comparison of FI rules and VI rules (i.e. Dome Rule and Increasing Interval

Rule) across three different cost coefficients, all Post hoc test (Tukey HSD) results show that the difference in performance is not statistically significant. Thus, the fixed interval rules and the variable interval rules are not significantly different in getting a lower expected total cost for Moderate Procedures. The results are shown in Appendix F Table F 1 to Table F 3.

4.3.2 Case 3 Scenario 2 Partially Shared ORs with No Emergency Cases

As Table 8 shows, OR 1 and OR 2 are allocated to only Moderate Procedures. Therefore, the results are the same as those in Section 4.3.1 for Case 3 Scenario 1. OR 3 performs only Long Procedures. The results for this allocation are provided in Table 26 in Section 4.2.1 for Case 2 Scenario 1. OR 4 to OR 6 perform six Short Procedures and one Long Procedure, and this combination is the same as the one in Case 2 Scenario 2. The results can be seen in Section 4.2.2.

4.3.3 Case 3 Scenario 3 Shared ORs with No Emergency Cases

For Scenario 3, which is different from previous experiments, two different combinations for three surgery types (see Table 8) are tested. OR 1 to OR 4, which perform four Short Procedures, one Moderate Procedure, and one Long Procedure, are defined as Combination 1. OR 5 to OR 6, which performs one Short Procedure, two Moderate Procedures, and one Long Procedure, are defined as Combination 2.

Similar to previous experiments, the best FI rules from Scenario 1 are used. The results of Combination 1 are shown in Table 39. Visual comparisons of the sequencing rules can be seen in Figure 14. The SPT rule (409.71 ± 29.96, 590.28 ± 51.86, 789.12 ± 72.99) performs the best in overall performance while the LPT rule (556.46 ± 38.81, 822.72 ± 61.35, 1037.96 ± 82.95) has the highest expected total cost across three cost coefficients levels. The results of the four alternated rules are in between. All Post hoc tests (Tukey HSD) show that the expected total cost is statistically significantly lower in the SPT rule compared to other five rules when c_{it}, c_o= 5 and

10, thus indicating that the SPT rule makes a significant improvement in overall performance. When c_{it}, c_o= 15, the difference in performance is not statistically significant between the SPT rule and AR 3 or AR 4, but the SPT rule still makes significant improvement compared to LPT rule, AR 1 and AR 2. In addition, it can be noted that there is no statistically significant difference between the four alternated rules across three cost coefficients levels. The ANOVA results are in Appendix F Table F 4 to Table F 6.

Figure 14

Scenario 3 Comparison of Sequencing Rules in Combination 1 (c_{it}, c_o= 5, 10, 15)

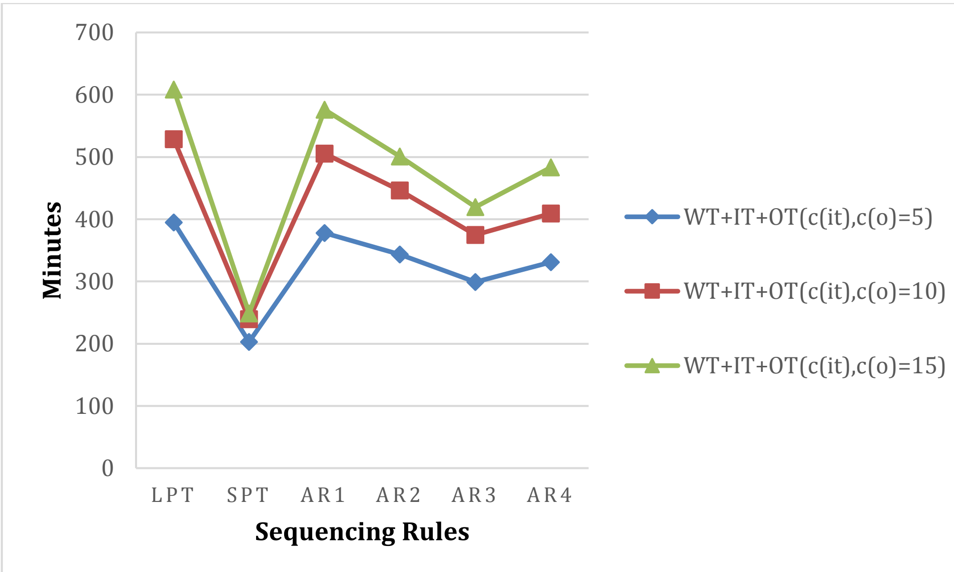


Table 39

Scenario 3, Combination 1, Comparison of Sequencing Rules (c_{it}, c_o= 5, 10, 15)

	LPT	SPT	AR1	AR2	AR3	AR4
Performance Measure	**Average, 95% C.I.**					
c_{it}, c_o= 5						
Total Waiting Time (min)	354.28 ± 22.83	151.20 ± 12.91	336.81 ± 21.77	296.11 ± 19.03	248.30 ± 15.94	288.90 ± 20.8
Total Idle Time (min)	10.37 ± 1.81	16.68 ± 1.45	10.95 ± 1.85	14.74 ± 1.76	16.56 ± 1.66	11.48 ± 1.81
Overtime (min)	30.07 ± 4.22	35.02 ± 4.41	30.27 ± 4.24	32.49 ± 4.38	34.19 ± 4.4	30.52 ± 4.25
Utilization	0.77 ± 0.01	0.77 ± 0.01	0.77 ± 0.01	0.77 ± 0.01	0.77 ± 0.01	0.77 ± 0.01
WT5IT5OT	556.46 ± 38.81	409.71 ± 29.96	542.91 ± 37.76	532.30 ± 36.2	502.04 ± 33.98	498.91 ± 35.27
c_{it}, c_o= 10						
Total Waiting Time (min)	496.04 ± 25.38	200.32 ± 14.23	472.52 ± 24.38	409.68 ± 21.06	335.99 ± 17.48	374.4 ± 22.95
Total Idle Time (min)	3.43 ± 0.87	7.44 ± 0.82	3.59 ± 0.9	6.15 ± 0.89	7.27 ± 0.87	5.12 ± 1.12
Overtime (min)	29.24 ± 4.19	31.56 ± 4.3	29.31 ± 4.2	30.65 ± 4.28	31.37 ± 4.3	29.51 ± 4.22
Utilization	0.79 ± 0.01	0.78 ± 0.01	0.79 ± 0.01	0.78 ± 0.01	0.78 ± 0.01	0.78 ± 0.01
WT10IT10OT	822.72 ± 61.35	590.28 ± 51.86	801.54 ± 60.4	777.70 ± 58.57	722.40 ± 56.2	720.76 ± 57.22
c_{it}, c_o= 15						
Total Waiting Time (min)	577.64 ± 26.32	209.96 ± 14.27	544.82 ± 25.22	465.23 ± 21.59	382.53 ± 17.83	452.10 ± 24.27
Total Idle Time (min)	1.54 ± 0.51	7.08 ± 0.78	1.83 ± 0.56	4.85 ± 0.64	5.96 ± 0.68	2.16 ± 0.63
Overtime (min)	29.15 ± 4.19	31.53 ± 4.3	29.16 ± 4.19	30.58 ± 4.27	31.15 ± 4.29	29.20 ± 4.19
Utilization	0.79 ± 0.01	0.78 ± 0.01	0.79 ± 0.01	0.79 ± 0.01	0.78 ± 0.01	0.79 ± 0.01
WT15IT15OT	1037.96 ± 82.95	789.12 ± 72.99	1009.72 ± 81.62	996.69 ± 80.07	939.14 ± 77.81	922.37 ± 78.83

For Combination 2, the results are similar to Combination 1 in that the SPT rule results in lowest expected total cost, while the LPT rule gets the highest expected total cost when c_{it}, c_o= 5, 10 and 15. The results of the four alternated rules are in between. The comparison can be seen in Table 40. The line graph is in Figure 15. All Post hoc tests (Tukey HSD) show that the expected total cost is statistically significantly lower in the SPT rule compared to LPT rule and AR 4 when

c_{it}, c_o= 5 and 10, thus indicating that the SPT rule makes a significant improvement in overall performance. When c_{it}, c_o= 15, the statistically significant difference only between the SPT rule and LPT rule. Also, the difference in performance is not statistically significant between the four alternated rules across three cost coefficients levels. The ANOVA results are in Appendix F Table F 7 to Table F 9.

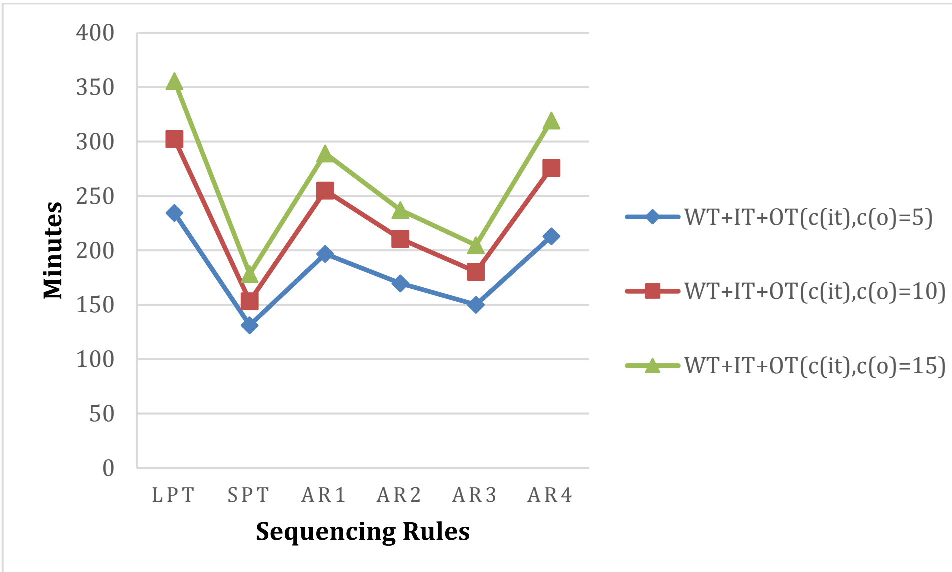
Table 40

Scenario 3, OR Combination 2, Comparison of Sequencing Rules (c_{it}, c_o= 5, 10, 15)

	LPT	SPT	AR1	AR2	AR3	AR4
Performance Measure	**Average, 95% C.I.**					
c_{it}, c_o= 5						
Total Waiting Time (min)	210.72 ± 14.05	102.92 ± 9.16	172.98 ± 12.61	141.57 ± 10.06	120.52 ± 9.18	189.3 ± 13.64
Total Idle Time (min)	9.44 ± 1.62	12.9 ± 1.27	9.73 ± 1.65	12.99 ± 1.51	14.08 ± 1.48	9.5 ± 1.64
Overtime (min)	14.17 ± 3.26	15.39 ± 3.38	14.13 ± 3.25	15.29 ± 3.35	15.39 ± 3.38	14.17 ± 3.26
Utilization	0.74 ± 0.01	0.74 ± 0.01	0.74 ± 0.01	0.73 ± 0.01	0.73 ± 0.01	0.74 ± 0.01
WT5IT5OT	328.8 ± 25.71	244.35 ± 22.79	292.25 ± 23.4	282.96 ± 22.68	267.88 ± 22.37	307.65 ± 24.55
c_{it}, c_o= 10						
Total Waiting Time (min)	285.27 ± 15.45	132.82 ± 9.84	237.86 ± 14.06	190.48 ± 11.03	159.46 ± 9.99	258.88 ± 15.09
Total Idle Time (min)	3.2 ± 0.8	5.9 ± 0.73	3.41 ± 0.81	5.62 ± 0.76	6.12 ± 0.76	3.28 ± 0.81
Overtime (min)	13.87 ± 3.24	14.61 ± 3.3	13.87 ± 3.24	14.55 ± 3.29	14.61 ± 3.3	13.87 ± 3.24
Utilization	0.75 ± 0.01	0.75 ± 0.01	0.75 ± 0.01	0.75 ± 0.01	0.75 ± 0.01	0.75 ± 0.01
WT10IT10OT	455.96 ± 42.37	337.95 ± 39.19	410.75 ± 40.01	392.17 ± 39.09	366.75 ± 38.8	430.44 ± 41.11
c_{it}, c_o= 15						
Total Waiting Time (min)	340.52 ± 15.97	159.66 ± 10.11	273.53 ± 14.55	218.36 ± 11.29	186.15 ± 10.29	304.13 ± 15.63
Total Idle Time (min)	1.33 ± 0.43	4.08 ± 0.48	1.63 ± 0.5	4.31 ± 0.54	4.15 ± 0.49	1.41 ± 0.46
Overtime (min)	13.85 ± 3.24	14.57 ± 3.3	13.85 ± 3.24	14.55 ± 3.29	14.57 ± 3.3	13.85 ± 3.24
Utilization	0.76 ± 0.01	0.75 ± 0.01	0.76 ± 0.01	0.75 ± 0.01	0.75 ± 0.01	0.76 ± 0.01
WT15IT15OT	568.26 ± 58.82	439.32 ± 55.83	505.78 ± 56.38	501.27 ± 55.65	466.91 ± 55.5	533.04 ± 57.52

Figure 15

Scenario 3 Comparison of Sequencing Rules in Combination 1 (c_{it}, c_o= 5, 10, 15)



4.3.4 Case 3 Comparison of Three Scenarios with No Emergency Cases

The expected total costs for each scenario for all six ORs are shown in Table 41 for cost coefficients levels of five, ten and 15. In the comparison of three scenarios in three different cases, Scenario 3, "Shared ORs", has the lowest expected total cost with 2127.54 when c_{it}, c_o= 5, 2446.74 when c_{it}, c_o= 10, and 4035.12 when c_{it}, c_o= 15. Therefore, an allocation rule that uses all ORs to multiple surgery types gets the best result compared to other allocation rules in Case 3. This finding is consistent with that in Case 2.

Table 41

Expected total cost for Case 3 (c_{it}, c_o= 5, 10, 15)

		Short Procedures (52.8 Minutes)	Moderate Procedures (106 minutes)	Long Procedures (153 Minutes)	Total OR Time	Expected Total Cost $c_{it}, c_o = 5$	Expected Total Cost $c_{it}, c_o = 10$	Expected Total Cost $c_{it}, c_o = 15$
Scenario 1	OR 1 - 2	9			477 * 2	552.09 * 2	773.29 * 2	950.59 * 2
	OR 3 - 4		4		424 * 2	290.89 * 2	405.59 * 2	505.55 * 2
	OR 5 – 6			3	459 * 2	333.40 * 2	513.25 * 2	675.51 * 2
	Total				**2720**	**2352.76**	**3384.26**	**4263.3**
Scenario 2	OR 1 - 2		4		424 * 2	290.89 * 2	405.59 * 2	505.55 * 2
	OR 3			3	459	333.40	513.25	675.51
	OR 4 - 6	6		1	471* 3	458.54 * 3	657.93 * 3	862.48 * 3
	Total				**2720**	**2290.8**	**3298.22**	**4274.05**
Scenario 3	OR 1 - 4	4	1	1	471* 4	409.71 * 4	590.28 * 4	789.12 * 4
	OR 5 - 6	1	2	1	418 * 2	224.35 * 2	337.95 * 2	439.32 * 2
	Total				**2720**	**2127.54**	**2446.74**	**4035.12**

4.3.5 Case 3 Scenario 1 Dedicated ORs with Emergency Cases

As shown in Table 8, OR 1 and OR 2 perform to Short Procedures, and OR 5 and OR 6 perform Long Procedures. Therefore, the results are the same as those in Section 4.2.5 for Case 2 Scenario 1 when the probability of emergency arrivals is set at 10% emergency rate. OR 3 and OR 4 are allocated to Moderate Procedures and the results are provided in this section.

After adding 10% emergency case, the conclusions are similar to the conclusions in Section 4.3.1. The results for best fixed and variable interval rules for Moderate Procedures are given in Table 42. Increasing Interval Rule (VI 16, VI 17, VI 17) still performs best in getting the lowest expected total cost. In a comparison of FI rules and VI rules (i.e. Dome Rule and Increasing Interval Rule) across three different cost coefficients (i.e. five, ten and 15), all Post hoc test (Tukey HSD) results show that the difference in performance is not statistically significant, thus indicating that the fixed interval rules and the variable interval rules are not significantly different in resulting lower expected total cost for Moderate Procedures. The results are shown in Appendix F Table F 10 to Table F 12.

Table 42

Scenario 1, Comparison of Best Rule in FI and VI for Moderate Procedures (c_{it}, c_o= 5, 10, 15)

	Fixed Interval	Dome Rule	Increasing Interval
Performance Measure	**Average, 95% C.I.**		
c_{it}, c_o= 5			
	FI 5	**VI 13**	**VI 16**
Total Waiting Time (min)	181.07 ± 15.62	204.98 ± 15.77	188.93 ± 15.78
Total Idle Time (min)	10.65 ± 1.41	6.06 ± 0.99	7.68 ± 1.25
Overtime (min)	47.35 ± 7.47	46.26 ± 7.41	46.39 ± 7.41
Utilization	1.00 ± 0	1.00 ± 0	1.00 ± 0
WT5IT5OT	471.09 ± 46.63	466.57 ± 46.65	459.28 ± 46.63
c_{it}, c_o= 10			
	FI 7	**VI 14**	**VI 17**
Total Waiting Time (min)	218.95 ± 15.81	249.19 ± 16.15	231.14 ± 16.12
Total Idle Time (min)	4.52 ± .78	1.79 ± 0.45	2.30 ± 0.6
Overtime (min)	46.13 ± 7.40	45.52 ± 7.37	45.55 ± 7.37
Utilization	1.00 ± 0	1.00 ± 0	1.00 ± 0
WT10IT10OT	725.46 ± 82.39	722.29 ± 82.72	709.64 ± 82.64
c_{it}, c_o= 15			
	FI 9	**VI 14**	**VI 17**
Total Waiting Time (min)	264.65 ± 15.72	249.19 ± 16.15	231.14 ± 16.12
Total Idle Time (min)	1.25 ± .32	1.79 ± 0.45	2.30 ± 0.6
Overtime (min)	45.48 ± 7.37	45.52 ± 7.37	45.55 ± 7.37
Utilization	1.00 ± 0	1.00 ± 0	1.00 ± 0
WT15IT15OT	965.57 ± 118.68	958.83 ± 118.99	948.89 ± 118.87

4.3.6 Case 3 Scenario 2 Partially Shared ORs with Emergency Cases

As Table 8 shows, OR 1 and OR 2 perform only Moderate Procedures. The results for this allocation are provided in Section 4.3.5 for Case 3 Scenario 1. OR 3 are allocated to Long Procedures. Thus, the results are the same as those in Table 31 in Section 4.2.5 for Case 2 Scenario 1. OR 4 to OR 6 perform six Short Procedures and one Long Procedure. The results for this combination can be seen in Section 4.2.6 for Case 2 Scenario 2.

4.3.7 Case 3 Scenario 3 Shared ORs with Emergency Cases

In Scenario 3, the SPT rule is the best rule in getting the lowest total expected cost, while the LPT rule results in highest lowest expected total cost across three cost coefficients levels in Combination 1 and Combination 2. Detailed results are given in Table 43 and Table 44. Visual comparisons are shown in Figure 16 and Figure 17. In a comparison of these six sequencing rules, results show that the difference in performance is not statistically significant between these rules regarding three levels of cost coefficients, thus it can be said that changing sequencing rules in scenarios 3 would not make a significant improvement in performance after adding the emergency cases. The results can be seen in the Appendix F Table F 13 to Table F 18.

Table 43

Scenario 3, Combination 1, Comparison of Sequencing Rules (c_{it}, c_o= 5, 10, 15)

	LPT	SPT	AR1	AR2	AR3	AR4
Performance Measure	**Average, 95% C.I.**					
c_{it}, c_o= 5						
Total Waiting Time (min)	421.64 ± 26.76	254.59 ± 24.24	413.54 ± 26.98	383.82 ± 27.43	340.55 ± 26.20	369.11 ± 25.88
Total Idle Time (min)	8.58 ± 1.60	13.09 ± 1.30	9.11 ± 1.62	12.34 ± 1.55	13.24 ± 1.41	9.33 ± 1.60
Overtime (min)	79.04 ± 9.36	83.11 ± 9.43	79.29 ± 9.35	81.61 ± 9.41	82.57 ± 9.40	79.5 ± 9.38
Utilization	1.00 ± 0	1.00 ± 0	1.00 ± 0	1.00 ± 0	1.00 ± 0	1.00 ± 0
WT5IT5OT	859.73 ± 65.81	735.62 ± 64.13	855.55 ± 65.91	853.57 ± 67.03	819.62 ± 65.81	813.23 ± 64.46
c_{it}, c_o= 10						
Total Waiting Time (min)	546.44 ± 28.21	298.76 ± 24.05	530.94 ± 27.78	482.37 ± 27.43	425.53 ± 26.63	467.09 ± 25.71
Total Idle Time (min)	2.85 ± 0.77	5.94 ± 0.73	2.89 ± 0.77	5.21 ± 0.78	5.83 ± 0.74	2.92 ± 0.77
Overtime (min)	76.94 ± 9.31	79.39 ± 9.36	76.96 ± 9.31	78.54 ± 9.33	79.13 ± 9.35	77.03 ± 9.31
Utilization	1.00 ± 0	1.00 ± 0	1.00 ± 0	1.00 ± 0	1.00 ± 0	1.00 ± 0
WT10IT10OT	1344.25 ±111.21	1152.02 ±109.66	1329.39 ±111.07	1319.83 ±111.63	1275.06 ± 112	1266.57 ±108.43
c_{it}, c_o= 15						
Total Waiting Time (min)	617.43 ± 27.9	307.51 ± 23.97	592.73 ± 27.29	532.24 ± 27.35	466.18 ± 26.3	504.95 ± 25.71
Total Idle Time (min)	1.26 ± 0.44	5.78 ± 0.7	1.45 ± 0.47	4.17 ± 0.57	4.98 ± 0.61	1.64 ± 0.53
Overtime (min)	76.46 ± 9.3	79.31 ± 9.36	76.53 ± 9.3	78.26 ± 9.33	78.82 ± 9.35	76.6 ± 9.3
Utilization	1.00 ± 0	1.00 ± 0	1.00 ± 0	1.00 ± 0	1.00 ± 0	1.00 ± 0
WT15IT15OT	1783.32 ±156.38	1583.77 ±155.49	1762.39 ±156.21	1768.64 ±157.42	1723.25 ±157.58	1678.55 ±154.19

Figure 16

Scenario 3 Comparison of Sequencing Rules in Combination 1 (c_{it}, c_o= 5, 10, 15)

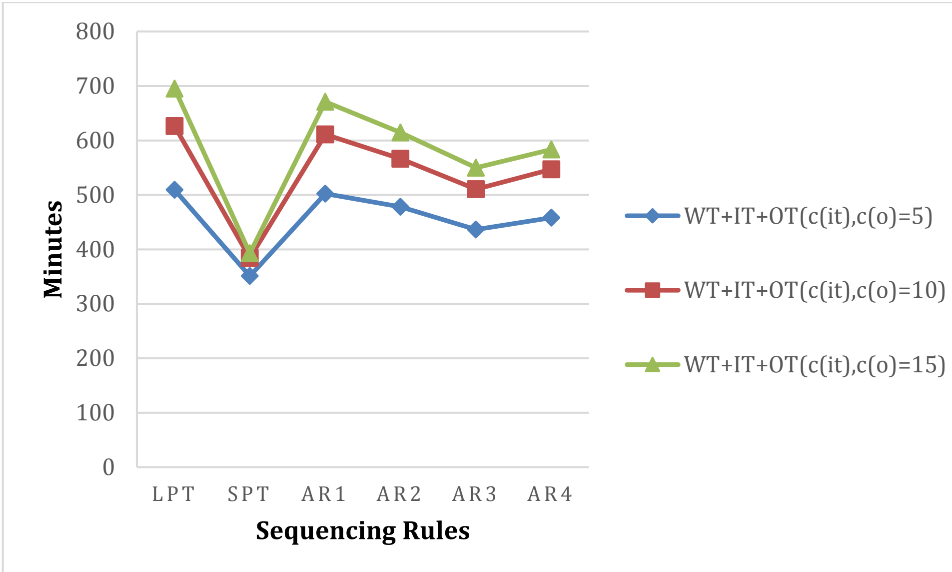


Figure 17

Scenario 3 Comparison of Sequencing Rules in Combination 2 (c_{it}, c_o= 5, 10, 15)

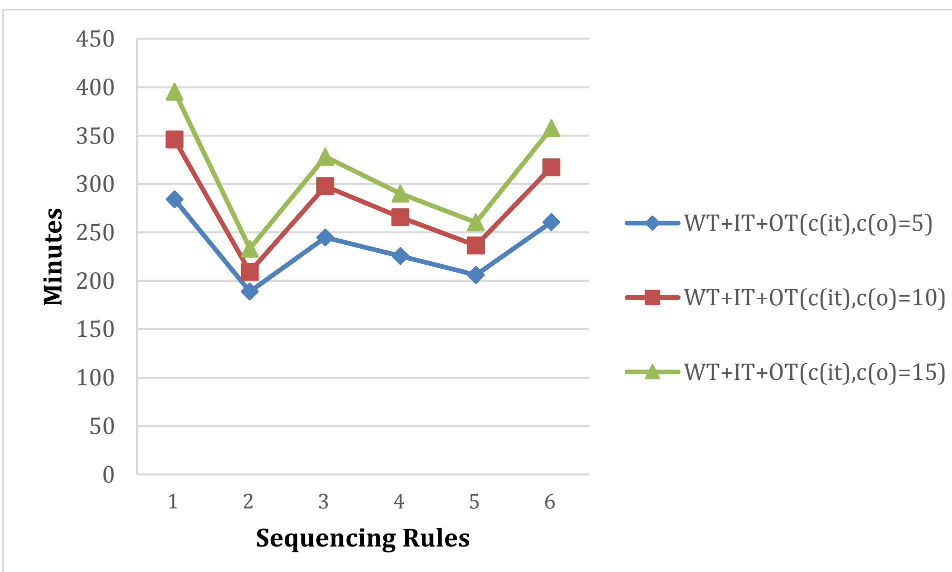


Table 44

Scenario 3, OR Combination 2, Comparison of Sequencing Rules (c_{it}, c_o= 5, 10, 15)

	LPT	SPT	AR1	AR2	AR3	AR4
Performance Measure	**Average, 95% C.I.**					
c_{it}, c_o= 5						
Total Waiting Time (min)	236.46 ± 15.69	137.41 ± 13.42	197.03 ± 13.87	174.19 ± 14.23	153.65 ± 13.42	212.85 ±14.97
Total Idle Time (min)	8.42 ± 1.49	11 ± 1.2	8.56 ± 1.51	11.05 ± 1.38	11.93 ± 1.35	8.47 ± 1.5
Overtime (min)	39.18 ± 6.74	40.46 ± 6.84	39.17 ± 6.75	40.45 ± 6.81	40.52 ± 6.84	39.21 ± 6.75
Utilization	1.00 ± 0	1.00 ± 0	1.00 ± 0	1.00 ± 0	1.00 ± 0	1.00 ± 0
WT5IT5OT	474.45 ± 43.23	394.69 ± 42.39	435.64 ± 41.4	431.66 ± 42.55	415.88 ± 41.99	451.28 ± 41.89
c_{it}, c_o= 10						
Total Waiting Time (min)	304.74 ± 16.09	164.96 ± 13.66	256.52 ± 14.41	221.7 ± 14.64	191.98 ± 13.78	275.9 ± 15.61
Total Idle Time (min)	2.78 ± 0.71	5.14 ± 0.68	2.91 ± 0.73	4.78 ± 0.69	5.24 ± 0.69	2.85 ± 0.71
Overtime (min)	38.34 ± 6.68	39.23 ± 6.75	38.35 ± 6.69	39.18 ± 6.74	39.24 ± 6.75	38.35 ± 6.68
Utilization	1.00 ± 0	1.00 ± 0	1.00 ± 0	1.00 ± 0	1.00 ± 0	1.00 ± 0
WT10IT10OT	715.97 ±75.23	608.65 ± 75.1	669.13 ± 74.04	661.26 ± 75.48	636.86 ± 75.22	687.9 ± 74.2
c_{it}, c_o= 15						
Total Waiting Time (min)	356.03 ± 16.4	190.55 ± 13.77	288.69 ± 14.58	247.19 ± 14.66	217.45 ± 13.94	318.37 ± 15.94
Total Idle Time (min)	1.15 ± 0.39	3.65 ± 0.46	1.39 ± 0.46	3.81 ± 0.51	3.68 ± 0.47	1.19 ± 0.4
Overtime (min)	38.14 ± 6.67	39.08 ± 6.74	38.15 ± 6.67	39.10 ± 6.74	39.08 ± 6.74	38.14 ± 6.67
Utilization	1.00 ± 0	1.00 ± 0	1.00 ± 0	1.00 ± 0	1.00 ± 0	1.00 ± 0
WT15IT15OT	945.48 ±108.31	831.48 ±108.71	881.82 ±106.79	890.92 ±108.71	858.83 ±108.84	908.43 ±107.42

4.3.8 Case 3 Comparison of Three Scenarios with Emergency Cases

The expected total costs of each scenario are given in Table 45 for cost coefficients levels of five, ten and 15. In the comparison of three scenarios in three different cases, Scenario 3, "Shared ORs", performs the best in getting the lowest expected total cost compared to other scenarios. This finding is similar to that in Case 2.

Table 45

Expected total cost for Case 3 (c_{it}, c_o= 5, 10, 15)

		Short Procedures (52.9 Minutes)	Moderate Procedures (106 minutes)	Long Procedures (153 Minutes)	Total OR Time	Expected Total Cost $c_{it}, c_o = 5$	Expected Total Cost $c_{it}, c_o = 10$	Expected Total Cost $c_{it}, c_o = 15$
Scenario 1	OR 1 - 2	9			477 * 2	1198.88 * 2	1815.71 * 2	2379.54 * 2
	OR 3 - 4		4		424 * 2	471.09 * 2	725.46 * 2	965.57 * 2
	OR 5 – 6			3	459 * 2	463.85 * 2	760.18 * 2	1038.67 * 2
	Total				**2720**	**4267.64**	**6602.7**	**8767.56**
Scenario 2	OR 1 - 2		4		424 * 2	471.09 * 2	725.46 * 2	965.57 * 2
	OR 3			3	459	463.85	760.18	1038.67
	OR 4 - 6	6		1	471* 3	901.19 * 3	1414.58 * 3	1923.90 * 3
	Total				**2720**	**4109.6**	**6454.84**	**8741.51**
Scenario 3	OR 1 - 4	4	1	1	471* 4	735.62 * 4	1152.02 * 4	1583.77 * 4
	OR 5 - 6	1	2	1	418 * 2	394.69 * 2	608.65 * 2	831.48 * 2
	Total				**2720**	**3731.86**	**5825.38**	**7998.04**

4.3.9 Key Insights from Case 3

Table 46 provides a summary of the results tested in Case 3 that uses the data from CIHI and performs three procedure types. In Scenario 1, the results are similar to those in Case 1 and Case 2 in that the VI rules produce a lower expected total cost. However, the improvement in performance among the VI rules is not statistically significant. Thus, the fixed interval rules and the variable interval rules are not significantly different in improving overall performance. In Scenario 2 and Scenario 3, the SPT rule has significant improvement over other sequencing rules in overall performance with no emergency cases. With the arrival of emergency cases, the SPT rule only results in a significant improvement when c_{it}, c_o= 5 in Scenario 2. Scenario 3, "Shared ORs", results in lowest expected total cost, therefore, it is the ideal allocation rule for Case 3. This finding is consistent with that in Case 2.

Table 46

Summary of Results in Case 3

Factors					Results				
					0% Emergency Cases		10% Emergency Cases		
Scenarios	**ORs Allocations**	**Appointment Rules**	**Sequencing Rules**	**Cost Coefficients for Idle Time, Overtime**	**Appointment Rules**	**Sequencing Rules**	**Appointment Rules**	**Sequencing Rules**	**Expected Total Cost**
Scenario 1: Dedicated ORs	OR 1 - 2: 9 SP only	FI, VI	N/A	5	VI	N/A	VI	N/A	Highest
				10	VI	N/A	VI	N/A	
				15	VI	N/A	VI	N/A	
	OR 3 - 4: 4 MP only	FI, VI	N/A	5	VI	N/A	VI	N/A	
				10	VI	N/A	VI	N/A	
				15	VI	N/A	VI	N/A	
	OR 5 - 6: 3 LP only	FI, VI	N/A	5	VI	N/A	VI	N/A	
				10	VI	N/A	VI	N/A	
				15	VI	N/A	VI	N/A	
Scenario 2: Partially Shared ORs	OR 1 - 2: 4 MP only	FI, VI	N/A	5	VI	N/A	VI	N/A	
				10	VI	N/A	VI	N/A	
				15	VI	N/A	VI	N/A	
	OR 3: 3 LP only	FI, VI	N/A	5	VI	N/A	VI	N/A	
				10	VI	N/A	VI	N/A	
				15	VI	N/A	VI	N/A	
	OR 4 - 6: 6 SP + 1 LP	FI	LPT, SPT, AR 3	5	FI	SPT*	FI	SPT*	
				10	FI	SPT*	FI	SPT	
				15	FI	SPT*	FI	SPT	
Scenario 3: Shared ORs	OR 1 - 3: 4 SP + 1 MP + 1 LP	FI	LPT, SPT, AR 1 – AR 4	5	FI	SPT*	FI	SPT	Lowest
				10	FI	SPT*	FI	SPT	
				15	FI	SPT*	FI	SPT	
	OR 4 - 6: 1 SP + 2 MP + 1 LP	FI	LPT, SPT, AR 1 – AR 4	5	FI	SPT*	FI	SPT	
				10	FI	SPT*	FI	SPT	
				15	FI	SPT*	FI	SPT	

*. The mean difference is significant at the 0.05 level.
SP ~ Short Procedure, 30 + Exponential (22.9)
MP ~ Moderate Procedure, 47 + GAMMA (29.2, 2.03)
LP ~ Long Procedure, 44 + 254 * BETA (1.98, 2.62)

5. Conclusion

Scheduling surgery cases is a complex task because of the significant uncertainty that exists in the OR system. Variability in surgery procedure duration, multiple surgery types, and the arrival of emergency cases complicate the design of effective schedules. This paper develops surgery scheduling policies for elective and emergency surgeries with the objective of reducing patient waiting time, surgeon idle time and surgery overtime. Simulation models are created to study multiple operating rooms' schedule for a given session. Using the data from previous literature and from Canadian Institute for Health Information (CIHI), the three cases with three different scenarios (three allocation rules) each are simulated. Two different interval rules, six different sequencing policies, different levels of cost coefficient, two probabilities of emergency case arrival rate are simulated within each case to identify the scheduling policy that results in the best overall performance. The two interval rules consist of a set of fixed interval rules and variable interval rules. Six sequencing rules are also tested including longest processing time first (LPT), shortest processing time first (SPT), alternate rule 1 (AR 1), alternate rule 2 (AR 2), alternate rule 3 (AR 3) and alternate rule 4 (AR 4) in Table 6.

When only one type of procedure is performed in an OR, the trade-off between the surgeon and patient priority should be considered. A hospital usually considers surgeon satisfaction more important because the cost of the surgeon is usually higher than that of the patient. Therefore, if the cost coefficients of idle time and overtime are higher than that of patient waiting time, decreasing the interval length between cases can reduce surgeon idle time and overtime. This finding is consistent with research findings in other papers focusing on outpatient clinic scheduling and surgery scheduling (Klassen and Yoogalingam, 2009; Gul et al. 2011). In addition, the study found that there is no significant difference between Fixed Interval Rule, Increasing Interval Rule and Dome Rule in getting the lowest expected total cost with no emergency cases or 10% emergency case arrival rate. The Decreasing Interval Rule and Reverse Dome Rule always have worse performance.

When different types of procedures are performed in an OR, sequencing of these procedures is important. With no emergency cases, the SPT rule is found to be the best strategy that results in improving overall performance. This finding is consistent with research findings in other articles (Sciomachen et al., 2005; Testi et al., 2007; Olsen, 2015; Gul et al. 2011). The reason why the SPT rule outperforms other rules is because short procedures have less variability than longer procedures. The short procedures have smaller standard deviations. It would allow an OR scheduler to have a more accurate prediction in an OR schedule. ORs that start with short procedures have a higher chance that followed procedures will start on time (Lebowitz, 2003). If they are not started on time, there are less waiting times than ORs that begin with long procedures. In addition, this study has different cases with different surgery mean durations and it could provide a more detail analysis of the impact from different mean durations to sequencing rules.

In general, the SPT rule always reduces patient waiting time, which results in the lowest expected total cost with no emergency cases when surgery mean duration is relatively short. For the LPT rule, even though it always results in lowest idle time and overtime compared to other rules, an ideal sequencing policy needs to minimize the tradeoff between waiting time, idle time and overtime, making the LPT rule not an ideal policy. For the four alternated rules, most of the results indicate that there is no significant difference between them, and the SPT rule outperforms the four alternated rules.

For the arrival of emergency cases, previous studies mainly focused on operating room resource planning (Wullink et al., 2007; Azeri-Rad et al., 2014; Persson and Persson, 2010), but they did not consider the impact of emergency cases on sequencing rules. With 10% emergency case arrival rate, if the surgery mean duration is relatively long and fewer surgeries are scheduled, there is no significant difference between the SPT rule and other rules. When the surgery mean duration is relatively short, the SPT rule still improves the overall performance only when the cost coefficients of idle time and overtime is 5. It should be noted that, after incorporating the third procedure type, changing rules would not have a statistical difference in overall performance since none of the rules can offset the increase in the cost from both waiting time and overtime resulting from the arrival of emergency cases. The reason why most of the sequencing rules would not make an improvement on performance after the arrival of emergency cases is because the utilization is already very high due to the allocation rules in this study. Therefore, the arrival of emergency case would affect the performance of sequencing rules.

This study considers the impact from different cost coefficients of idle time and overtime to the best rule. Prior literature also focused on testing different cost coefficients in operating rooms (Denton et al., 2007; Astaraky and Patrick, 2015), but none of them studied its impact to sequencing rules while considered the arrival of emergency cases. With no emergency cases, if the surgery mean duration is relatively long, the SPT rule only has significant improvement when the cost coefficient of idle time and overtime is 5. When the surgery mean duration is relatively short and more procedures are scheduled, the SPT rule always has a significant impact on decreasing the expected total cost. The cost coefficients of idle time and overtime can be low (5) or high (15). With emergency arrival rate is 10%, the improvement from the SPT rule might not be significant.

In the comparison of three allocation rules in three different cases, different cases have the different best option. When surgery mean duration is relatively long, “Partially Shared ORs”, appears to be more effective in getting the lower total expected cost when either surgeon or patient priority is concerned. In “Partially Shared ORs”, it dedicates some ORs to a single procedure type and remaining ORs to multiple surgery types. Surgeries can be grouped by their durations first, and then similar duration surgeries are put in part of the ORs. The rest of the ORs can schedule different types of surgery. The scheduler can use the mean of surgery durations as the interval between cases to set up the OR schedule in the ORs that only have one procedure type. In the ORs that have more than one procedure type, the relatively shorter procedures should be processed first. When surgery mean duration is relatively short and more cases can be scheduled, the “Shared ORs”, which uses all ORs to multiple surgery types improve overall performance compared to other scenarios. Prior literature mainly used analytical methods to find the best combination of different procedure types (Ozkarahan, 2000; Kuo et al., 2003; Ogulata and Erol, 2003), but the allocation rules in this study that are based on surgery mean duration may also provide a different insight in surgery allocation rules.

6. Implication for Literature and Practice

This research adds to the prior literature in several ways. Firstly, it is the first study aiming to develop surgery scheduling policies for elective surgery cases and emergency cases by using simulation as an approach – previous studies usually used analytical methods such as integer programming, mixed integer programming, or linear programming. Secondly, this study considers varied factors including different distributions for surgery duration, multiple types of surgical procedures, and different levels of cost coefficient for idle time and overtime – prior literature has not simultaneously studied these factors. Thirdly, this research uses real data on surgery durations from the Canadian Institute for Health Information (CIHI) to empirically validate the performance of different policies. The data obtained may be valuable in providing further empirical support for the parameters of the OR scheduling problem.

From a practical standpoint, this study has provided some general insights that OR managers can use for developing surgery schedules. If a hospital needs to schedule the procedure types that have similar surgery durations, the Fixed Interval Rule, Increasing Interval Rule or Dome Rule can be used. The Fixed Interval Rule may be easier to set up for the scheduler in reality. If a hospital needs to schedule the procedure types that have different surgery mean durations, Shared ORs and the SPT rule are recommended to use if the mean duration is relatively short. If the surgery duration is relatively long, Partially Shared ORs would the best allocation rule and the SPT rule will make improvement only when the cost coefficients of idle time and overtime is low. It should be noted that, with 10% emergency case arrival rate, the improvement from the SPT rule might not be significant if the utilization is already very high.

However, this study has some limitations that could be improved by future research. The current model only includes the operative stage, and it does not involve pre-operative stage (pretesting and anesthesia) and post-operative stage (transfer to post anesthesia unit). How to organize different resources efficiently during those stages should be analyzed as well. Cases with additional characteristics can be tested to allow a more in depth comparison of scheduling policies. These were not conducted in this research due to lack of sufficient data. Another opportunity for improvement is to consider the transfer between operating rooms. For example, when a surgery could not be completed on time, the next case can be moved to another available OR if the surgeon is ready. Moreover, the probability of emergency cases in the current model is 10% and different emergency case arrival rates can be investigated further to find better allocation rules.

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Appendix A Simulation Results of Case 1

Table A 1

Case 1: FI for Short Procedures, $P_E = 0\%$

	FI 1	FI 2	FI 3	FI 4	FI 5
Performance Measure	**Average, 95% C.I.**				
Total Waiting Time (min)	91.34 ± 8.44	130.59 ± 9.97	180.85 ± 11.30	240.58 ± 12.25	306.85 ± 12.83
Total Idle Time (min)	26.08 ± 2.08	15.01 ± 1.55	7.82 ± 1.04	3.76 ± 0.68	1.70 ± 0.41
Overtime (min)	31.17 ± 2.99	25.57 ± 2.97	23.06 ± 2.93	21.81 ± 2.90	21.18 ± 2.87
Utilization	0.95 ± 0.00	0.97 ± 0.00	0.98 ± 0.00	0.99 ± 0.00	1.00 ± 0.00
WTITOT	148.6 ± 9.95	171.18 ± 11.79	211.73 ± 13.31	266.14 ± 14.37	329.73 ± 15.00
WT5IT5OT	377.61 ± 20.02	333.50 ± 21.86	335.25 ± 23.39	368.39 ± 24.51	421.23 ± 25.12
WT10IT10OT	663.87 ± 34.75	536.41 ± 36.18	489.65 ± 37.38	496.21 ± 38.35	535.62 ± 38.85
WT15IT15OT	950.14 ± 49.91	739.32 ± 50.91	644.05 ± 51.75	624.03 ± 52.54	650.00 ± 52.90
WT20IT20OT	1236.4 ± 65.20	942.23 ± 65.78	798.45 ± 66.25	751.84 ± 66.86	764.38 ± 67.08

Table A 2

Case 1: VI for Short Procedures, $P_E = 0\%$

	Dome Rule				**Reverse Dome Rule**				**Increasing Interval Rule**				**Decreasing Interval Rule**			
	VI 1	**VI 2**	**VI 3**	**VI 4**	**VI 5**	**V I6**	**VI 7**	**VI 8**	**VI 9**	**VI 10**	**VI 11**	**VI 12**	**VI 13**	**VI 14**	**VI 15**	**VI 16**
Performance Measure	**Average, 95% C.I.**															
Total Waiting Time (min)	135.56 ± 10.20	188.11 ± 11.56	249.69 ± 12.53	318.50 ± 13.02	128.51 ± 9.76	175.50 ± 10.68	233.89 ± 11.89	297.79 ± 12.52	350.58 ± 13.27	278.84 ± 12.97	211.48 ± 12.32	153.08 ± 11.10	337.73 ± 12.53	273.62 ± 11.93	215.40 ±11.13	164.90 ± 10.10
Total Idle Time (min)	13.05 ± 1.49	6.33 ± 0.97	2.59 ± 0.59	1.03 ± 0.33	17.59 ± 1.61	12.73 ± 1.25	5.42 ± 0.80	2.89 ± 0.53	0.36 ± 0.16	1.27 ± 0.39	3.93 ± 0.78	10.02 ± 1.38	2.85 ± 0.53	5.22 ± 0.77	9.03 ± 1.06	14.97 ± 1.39
Overtime (min)	24.47 ± 2.93	22.28 ± 2.90	21.33 ± 2.87	20.91 ± 2.86	27.11 ± 3.03	25.73 ± 3.03	22.55 ± 2.93	21.64 ± 2.89	20.74 ± 2.85	20.91 ± 2.86	21.36 ± 2.87	22.62 ± 2.89	21.64 ± 2.89	22.55 ± 2.93	24.16 ± 2.97	26.77 ± 3.04
Utilization	0.97 ± 0.00	0.99 ± 0.00	0.99 ± 0.00	1.00 ± 0.00	0.96 ± 0.00	0.97 ± 0.0	0.99 ± 0.00	0.99 ± 0.00	1.00 ± 0	1.00 ± 0.00	0.99 ± 0.00	0.98 ± 0.00	0.99 ± 0.00	0.99 ± 0.00	0.98 ± 0.00	0.97 ± 0.00
WTITOT	173.07 ± 11.97	216.73 ± 13.53	273.60 ± 14.64	340.44 ± 15.18	173.22 ± 11.66	213.96 ± 12.81	261.86 ± 14.04	322.32 ± 14.70	371.68 ±15.46	301.02 ±15.11	236.77 ± 14.32	185.73 ± 12.81	362.22 ± 14.71	301.39 ± 14.09	248.59 ±13.27	206.63 ± 12.19
WT5IT5OT	323.12 ± 21.75	331.17 ± 23.39	369.28 ± 24.67	428.20 ± 25.24	352.05 ± 22.10	367.79 ± 23.60	373.72 ± 24.35	420.43 ± 24.91	456.08 ±25.53	389.74 ± 25.11	337.92 ± 24.05	316.32 ± 22.10	460.18 ± 24.93	412.47 ±24.45	381.32 ±23.87	373.57 ± 23.03
WT10IT10OT	510.68 ± 35.71	474.22 ± 37.07	488.87 ± 38.35	537.90 ± 38.86	575.59 ± 36.84	560.09 ± 38.47	513.55 ± 38.46	543.07 ± 38.78	561.59 ±39.13	500.63 ± 38.69	464.37 ± 37.51	479.55 ± 35.45	582.63 ± 38.82	551.33 ±38.59	547.24 ± 38.42	582.24 ± 38.05
WT15IT15OT	698.24 ± 50.12	617.28 ± 51.15	608.47 ± 52.38	647.61 ± 52.81	799.12 ± 51.98	752.39 ± 53.70	653.38 ± 52.91	665.71 ±52.99	667.09 ±53.06	611.53 ± 52.60	590.81 ± 51.35	642.79 ± 49.28	705.08 ± 53.03	690.18 ± 53.07	713.16 ± 53.32	790.92 ±53.42
WT20IT20OT	885.80 ± 64.68	760.33 ± 65.36	728.06 ± 66.53	757.31 ± 66.88	1022.7± 67.25	944.69 ± 69.05	793.21 ±67.48	788.35 ± 67.32	772.60 ± 67.1	722.42 ± 66.64	717.25 ± 65.33	806.03 ± 63.28	827.53 ± 67.36	829.04 ± 67.67	879.07 ± 68.35	999.59 ±68.91

Table A 3

Case 1: FI and VI for Long Procedures, $P_E = 0\%$

	Fixed Interval Rule								Increasing Interval Rule			Decreasing Interval Rule		
	FI 1	**FI 3**	**FI 5**	**FI 7**	**FI 9**	**FI 11**	**FI 13**	**FI 15**	**VI 17**	**VI 18**	**VI 19**	**VI 20**	**VI 21**	**VI 22**
Performance Measure	**Average, 95% C.I.**													
Total Waiting Time (min)	39.55 ± 5.06	53.73 ± 5.78	71.68 ± 6.46	93.27 ± 7.04	117.62 ± 7.50	144.64 ± 7.77	172.98 ± 7.94	202.34 ± 8.02	108.38 ± 7.41	134.91 ± 7.74	163.08 ± 7.93	102.36 ± 7.13	127.23 ± 7.55	154.52 ± 7.79
Total Idle Time (min)	29.81 ± 2.71	19.4 ± 2.20	11.76 ± 1.66	6.51 ± 1.17	3.13 ± 0.76	1.41 ± 0.45	0.48 ± 0.25	0.15 ± 0.13	3.89 ± 0.89	1.68 ± 0.52	0.58 ± 0.27	5.6 ± 1.04	2.74 ± 0.69	1.29 ± 0.42
Overtime (min)	38.4 ± 4.36	33.47 ± 4.30	30.96 ± 4.27	29.75 ± 4.24	29.04 ± 4.23	28.74 ± 4.22	28.56 ± 4.21	28.48 ± 4.21	29.09 ± 4.22	28.74 ± 4.22	28.56 ± 4.21	29.7 ± 4.24	29.03 ± 4.23	28.74 ± 4.22
Utilization	0.94 ± 0.01	0.96 ± 0.01	0.97 ± 0.00	0.99 ± 0.00	0.99 ± 0.00	1 ± 0.00	1 ± 0.00	1 ± 0.00	0.99 ± 0.00	1 ± 0.00	1 ± 0.00	0.99 ± 0.00	0.99 ± 0.00	1 ± 0.00
WTITOT	107.77 ± 7.84	106.6 ± 8.64	114.4 ± 9.44	129.52 ±10.14	149.79 ±10.70	174.79 ±11.04	202.02 ±11.26	230.97 ±11.35	141.36 ±10.57	165.33 ±10.98	192.22 ±11.23	137.65 ±10.29	159.01 ±10.78	184.55 ±11.07
WT5IT5OT	380.63 ± 24.51	318.11 ± 24.58	285.29 ±25.12	274.55 ±25.78	278.48 ±26.42	295.38 ±26.82	318.19 ±27.10	345.47 ±27.21	273.27 ±26.19	287 ±26.72	308.78 ±27.05	278.84 ± 26	286.1 ±26.54	304.66 ±26.86
WT10IT10OT	721.7 ± 46.53	582.49 ± 45.67	498.89 ±45.84	455.84 ±46.38	439.33 ±47.05	446.12 ±47.49	463.4 ±47.84	488.61 ±47.96	438.15 ±46.74	439.08 ±47.37	454.48 ±47.77	455.31 ±46.67	444.97 ±47.22	454.8 ±47.56
WT15IT15OT	1062.78 ± 68.69	846.87 ± 66.93	712.49 ±66.72	637.12 ±67.14	600.19 ±67.86	596.85 ±68.34	608.62 ±68.74	631.74 ±68.87	603.04 ±67.46	591.17 ±68.18	600.18 ±68.65	631.79 ±67.50	603.84 ±68.07	604.94 ±68.42
WT20IT20OT	1403.85 ± 90.88	1111.25 ± 88.22	926.09 ±87.65	818.41 ±87.96	761.04 ±88.71	747.59 ±89.24	753.83 ±89.69	774.87 ±89.84	767.93 ±88.23	743.25 ±89.04	745.88 ±89.59	808.27 ±88.39	762.71 ±88.97	755.08 ±89.33

Table A 4

Case 1: FI and VI for Short Procedures, $P_E = 10\%$

	Fixed Interval Rule					**Dome Rule**				**Increasing Interval Rule**			
	FI 1	**FI 2**	**FI 3**	**FI 4**	**FI 5**	**VI 1**	**VI 2**	**VI 3**	**VI 4**	**VI 9**	**VI 10**	**VI 11**	**VI 12**
Performance Measure	**Average,95% C.I.**												
Total Waiting Time (min)	217.84 ±26.58	254.98 ± 26.14	302.72 ± 26.24	358.45 ± 26.33	416.05 ±26.26	259.49 ± 25.70	309.88 ± 26.14	365.73 ± 26.29	383.91 ± 26.21	454.18 ± 25.72	331.21 ± 26.23	275.76 ± 25.86	317.53 ± 26.07
Total Idle Time (min)	20.41 ± 1.97	12.05 ± 1.44	6.57 ± .99	3.37 ± .66	1.6 ± .41	10.3 ± 1.37	5.17 ± 0.9	2.27 ± 0.57	1.29 ± 0.4	0.36 ± 0.16	3.04 ± 0.7	7.4 ± 1.21	4.16 ± 0.85
Overtime (min)	93.91 ±10.00	88.52 ±10.04	85.7 ± 10.03	84.18 ±10.02	83.42 ± 10.00	87.27 ± 10.02	84.79 ± 10.02	83.59 ± 10	83.1 ± 9.99	82.79 ± 9.99	83.67 ± 10	85.2 ± 10.01	84.19 ± 10
Utilization	1.0 ± 0	1.0 ± 0	1.0 ± 0	1.0 ± 0	1.0 ± 0	1.0 ± 0	1.0 ± 0	1.0 ± 0	1.0 ± 0	1.0 ± 0	1.0 ± 0	1.0 ± 0	1.0 ± 0
WTITOT	332.15 ±33.77	355.55 ± 33.64	394.98 ±33.88	446.01 ± 34.00	501.06 ± 33.85	357.05 ± 33.19	399.84 ± 33.81	451.6 ± 33.97	468.3 ± 33.98	537.33 ± 33.28	417.93 ± 33.96	368.36 ± 33.42	405.88 ± 33.75
WT5IT5OT	789.4 ±68.88	757.83 ± 69.72	764.05 ±70.35	796.24 ± 70.64	841.1 ±70.42	747.32 ± 69.20	759.68 ± 70.32	795.06 ± 70.61	805.85 ± 70.76	869.9 ± 69.87	764.8 ± 70.59	738.7 ± 69.52	759.3 7±70.24
WT10IT10OT	1360.95 ±116.01	1260.67 ±117.80	1225.39 ±118.85	1234.02 ±119.36	1266.16 ±119.17	1235.15 ±117.18	1209.47 ±118.79	1224.38 ±119.31	1227.8 ±119.51	1285.67 ±118.64	1198.34 ±119.16	1201.74 ± 117.5	1201.01 ±118.66
WT15IT15OT	1932.51 ±163.85	1763.51 ±166.54	1686.72 ±167.97	1671.8 ±168.71	1691.21 ±168.57	1722.98 ±165.79	1659.27 ±167.87	1653.7 ±168.64	1649.74 ±168.85	1701.4 ±168.07	1631.9 ±168.34	1664.7 ±166.09	1642.7 ±167.69
WT20IT20OT	2504.06 ±211.92	2266.35 ±215.48	2148.06 ±217.30	2109.58 ±218.26	2116.27 ±218.18	2210.81 ±214.60	2109.07 ±217.15	2083.02 ±218.17	2071.68 ±218.39	2117.17 ± 217.7	2065.47 ±217.71	2127.72 ±214.87	2084.48 ±216.91

Table A 5

Case 1: Comparison of FI and VI for Long Procedures, $P_E = 10\%$

	Fixed Interval Rule								**Increasing Interval Rule**		
	FI 1	**FI 3**	**FI 5**	**FI 7**	**FI 9**	**FI 11**	**FI 13**	**FI 15**	**VI 17**	**VI 18**	**VI 19**
Performance Measure	**Average, 95% C.I.**										
Total Waiting Time (min)	61.08 ± 8.27	75.14 ± 8.7	89.52 ± 8.5	110.98 ± 8.99	130.4 ± 8.57	157.25 ± 8.78	184.46 ± 8.84	212.02 ± 8.54	215.65 ±8.3	147.55 ±8.75	175.12 ±8.88
Total Idle Time (min)	26.33 ± 2.71	17.37 ± 2.17	10.65 ± 1.64	6 ± 1.15	2.96 ± 0.75	1.33 ± 0.45	0.47 ± 0.25	0.15 ± 0.13	2.29 ±0.62	1.6 ±0.52	0.56 ±0.27
Overtime (min)	64.67 ± 7.76	59.84 ± 7.76	57.04 ± 7.74	55.58 ± 7.71	54.78 ± 7.68	54.4 ± 7.67	54.19 ± 7.66	54.1 ± 7.66	54.74 ±7.68	54.42 ±7.67	54.19 ±7.66
Utilization	1.0 ± 0	1.0 ± 0	1.0 ± 0	1.0 ± 0	1.0 ± 0	1.0 ± 0	1.0 ± 0	1.0 ± 0	1.0 ± 0	1.0 ± 0	1.0 ± 0
WTITOT	152.08 ± 13.74	152.35 ± 14.25	157.21 ± 14.16	172.55 ± 14.71	188.14 ± 14.21	212.98 ± 14.47	239.11 ± 14.57	266.27 ± 14.26	272.68 ±13.91	203.57 ±14.42	229.87 ±14.6
WT5IT5OT	516.08 ± 42.65	461.21 ± 43.11	427.97 ± 43.24	418.86 ± 43.77	419.11 ± 43.32	435.91 ± 43.61	457.71 ± 43.8	483.27 ± 43.56	500.78 ±43.09	427.66 ±43.54	448.86 ±43.8
WT10IT10OT	971.07 ± 80.25	847.28 ± 80.68	766.41 ± 80.97	726.74 ± 81.51	707.82 ± 81.13	714.58 ± 81.46	730.96 ± 81.73	754.51 ± 81.56	785.91 ±80.95	707.77 ±81.37	722.6 81.7
WT15IT15OT	1426.07 ± 118.04	1233.35 ± 118.45	1104.85 ± 118.88	1034.62 ±119.44	996.53 ± 119.12	993.24 ± 119.49	1004.21 ± 119.85	1025.76 ± 119.74	1071.03 ±119	987.89 ±119.39	996.34 ±119.8
WT20IT20OT	1881.07 ±155.88	1619.42 ± 156.26	1443.29 ± 156.84	1342.5 ± 157.42	1285.24 ± 157.15	1271.91 ± 157.58	1277.47 ± 158.02	1297.01 ± 157.97	1356.16 ±157.09	1268 ±157.46	1270.08 ±157.94

Appendix B ANOVA Results of Case 1

Table B 1

Case 1: Comparison of FI and VI for Short Procedures, $P_E = 0\%$

Dependent Variable: WT5IT5OT

Tukey HSD

(I) Rule	(J) Rule	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
FI2	VI1	10.38048	15.91777	.966	-33.0714	53.8323
	VI5	-18.54623	15.91777	.771	-61.9981	24.9056
	VI12	17.18706	15.91777	.817	-26.2648	60.6389
	VI16	-40.06684	15.91777	.087	-83.5187	3.3850
VI1	FI2	-10.38048	15.91777	.966	-53.8323	33.0714
	VI5	-28.92671	15.91777	.364	-72.3786	14.5251
	VI12	6.80658	15.91777	.993	-36.6453	50.2584
	VI16	-50.44732*	15.91777	.013	-93.8992	-6.9955
VI5	FI2	18.54623	15.91777	.771	-24.9056	61.9981
	VI1	28.92671	15.91777	.364	-14.5251	72.3786
	VI12	35.73329	15.91777	.164	-7.7186	79.1852
	VI16	-21.52061	15.91777	.659	-64.9725	21.9313
VI12	FI2	-17.18706	15.91777	.817	-60.6389	26.2648
	VI1	-6.80658	15.91777	.993	-50.2584	36.6453
	VI5	-35.73329	15.91777	.164	-79.1852	7.7186
	VI16	-57.25390*	15.91777	.003	-100.7058	-13.8020
VI16	FI2	40.06684	15.91777	.087	-3.3850	83.5187
	VI1	50.44732*	15.91777	.013	6.9955	93.8992
	VI5	21.52061	15.91777	.659	-21.9313	64.9725
	VI12	57.25390*	15.91777	.003	13.8020	100.7058

*. The mean difference is significant at the 0.05 level.

Table B 2

Case 1: Comparison of FI and VI for Short Procedures, $P_E = 0\%$

Dependent Variable: WT10IT10OT

Tukey HSD

(I) Rule	(J) Rule	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
FI3	VI2	15.42955	27.11527	.980	-58.5890	89.4480
	VI7	-23.89659	27.11527	.904	-97.9151	50.1219
	VI11	25.28568	27.11527	.884	-48.7328	99.3042
	VI15	-57.58596	27.11527	.210	-131.6045	16.4325
VI2	FI3	-15.42955	27.11527	.980	-89.4480	58.5890
	VI7	-39.32613	27.11527	.595	-113.3446	34.6924
	VI11	9.85614	27.11527	.996	-64.1624	83.8746
	VI15	-73.01551	27.11527	.055	-147.0340	1.0030
VI7	FI3	23.89659	27.11527	.904	-50.1219	97.9151
	VI2	39.32613	27.11527	.595	-34.6924	113.3446
	VI11	49.18227	27.11527	.366	-24.8362	123.2008
	VI15	-33.68938	27.11527	.726	-107.7079	40.3291
VI11	FI3	-25.28568	27.11527	.884	-99.3042	48.7328
	VI2	-9.85614	27.11527	.996	-83.8746	64.1624
	VI7	-49.18227	27.11527	.366	-123.2008	24.8362
	VI15	-82.87164*	27.11527	.019	-156.8901	-8.8531
VI15	FI3	57.58596	27.11527	.210	-16.4325	131.6045
	VI2	73.01551	27.11527	.055	-1.0030	147.0340
	VI7	33.68938	27.11527	.726	-40.3291	107.7079
	VI11	82.87164*	27.11527	.019	8.8531	156.8901

*. The mean difference is significant at the 0.05 level.

Table B 3

Case 1: Comparison of FI and VI for Short Procedures, $P_E = 0\%$

Dependent Variable: WT15IT15OT

Tukey HSD

(I) Rule	(J) Rule	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
FI4	VI3	15.55976	37.65346	.994	-87.2256	118.3451
	VI7	-29.35286	37.65346	.937	-132.1382	73.4325
	VI11	33.21604	37.65346	.904	-69.5693	136.0014
	VI14	-66.15887	37.65346	.399	-168.9442	36.6265
VI3	FI4	-15.55976	37.65346	.994	-118.3451	87.2256
	VI7	-44.91262	37.65346	.756	-147.6980	57.8727
	VI11	17.65628	37.65346	.990	-85.1291	120.4416
	VI14	-81.71863	37.65346	.191	-184.5040	21.0667
VI7	FI4	29.35286	37.65346	.937	-73.4325	132.1382
	VI3	44.91262	37.65346	.756	-57.8727	147.6980
	VI11	62.56891	37.65346	.458	-40.2164	165.3542
	VI14	-36.80601	37.65346	.865	-139.5913	65.9793
VI11	FI4	-33.21604	37.65346	.904	-136.0014	69.5693
	VI3	-17.65628	37.65346	.990	-120.4416	85.1291
	VI7	-62.56891	37.65346	.458	-165.3542	40.2164
	VI14	-99.37491	37.65346	.064	-202.1602	3.4104
VI14	FI4	66.15887	37.65346	.399	-36.6265	168.9442
	VI3	81.71863	37.65346	.191	-21.0667	184.5040
	VI7	36.80601	37.65346	.865	-65.9793	139.5913
	VI11	99.37491	37.65346	.064	-3.4104	202.1602

Table B 4

Case 1: Comparison of FI and VI for Long Procedures, $P_E = 0\%$

Dependent Variable: WT5IT5OT

Tukey HSD

(I) Rule	(J) Rule	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
FI7	VI17	1.28239	18.65665	.997	-42.4868	45.0516
	VI20	-4.28459	18.65665	.971	-48.0538	39.4846
VI17	FI7	-1.28239	18.65665	.997	-45.0516	42.4868
	VI20	-5.56697	18.65665	.952	-49.3362	38.2023
VI20	FI7	4.28459	18.65665	.971	-39.4846	48.0538
	VI17	5.56697	18.65665	.952	-38.2023	49.3362

Table B 5

Case 1: Comparison of FI and VI for Long Procedures, $P_E = 0\%$

Dependent Variable: WT10IT10OT

Tukey HSD

(I) Rule	(J) Rule	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
FI9	VI17	1.17614	33.74249	.999	-77.9850	80.3373
	VI21	-5.64242	33.74249	.985	-84.8036	73.5188
VI17	FI9	-1.17614	33.74249	.999	-80.3373	77.9850
	VI21	-6.81856	33.74249	.978	-85.9798	72.3426
VI21	FI9	5.64242	33.74249	.985	-73.5188	84.8036
	VI17	6.81856	33.74249	.978	-72.3426	85.9798

Table B 6

Case 1: Comparison of FI and VI for Long Procedures, $P_E = 0\%$

Dependent Variable: WT15IT15OT

Tukey HSD

(I) Rule	(J) Rule	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
FI11	VI18	5.68515	48.95579	.993	-109.1670	120.5373
	VI21	-6.99011	48.95579	.989	-121.8423	107.8621
VI18	FI11	-5.68515	48.95579	.993	-120.5373	109.1670
	VI21	-12.67526	48.95579	.964	-127.5274	102.1769
VI21	FI11	6.99011	48.95579	.989	-107.8621	121.8423
	VI18	12.67526	48.95579	.964	-102.1769	127.5274

Table B 7

Case 1: Comparison of Sequencing Rules in Scenario 2, $P_E = 0\%$

Dependent Variable: WT5IT5OT

Tukey HSD

(I) RULE	(J) RULE	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
LPT	SPT	39.76737	16.98859	.051	-.0885	79.6233
	AR3	-.14044	16.98859	1.000	-39.9963	39.7154
SPT	LPT	-39.76737	16.98859	.051	-79.6233	.0885
	AR3	-39.90780*	16.98859	.050	-79.7637	-.0519
AR3	LPT	.14044	16.98859	1.000	-39.7154	39.9963
	SPT	39.90780*	16.98859	.050	.0519	79.7637

*. The mean difference is significant at the 0.05 level.

Table B 8

Case 1: Comparison of Sequencing Rules in Scenario 2, $P_E = 0\%$

Dependent Variable: WT10IT10OT

Tukey HSD

(I) RULE	(J) RULE	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
LPT	SPT	52.09737	29.13642	.174	-16.2578	120.4525
	AR3	-2.70416	29.13642	.995	-71.0593	65.6510
SPT	LPT	-52.09737	29.13642	.174	-120.4525	16.2578
	AR3	-54.80153	29.13642	.145	-123.1567	13.5536
AR3	LPT	2.70416	29.13642	.995	-65.6510	71.0593
	SPT	54.80153	29.13642	.145	-13.5536	123.1567

Table B 9

Case 1: Comparison of Sequencing Rules in Scenario 2, $P_E = 0\%$

Dependent Variable: WT15IT15OT

Tukey HSD

(I) RULE	(J) RULE	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
LPT	SPT	84.46549	41.00691	.099	-11.7383	180.6693
	AR3	15.90784	41.00691	.920	-80.2960	112.1116
SPT	LPT	-84.46549	41.00691	.099	-180.6693	11.7383
	AR3	-68.55765	41.00691	.216	-164.7615	27.6462
AR3	LPT	-15.90784	41.00691	.920	-112.1116	80.2960
	SPT	68.55765	41.00691	.216	-27.6462	164.7615

Table B 10

Case 1: Comparison of Sequencing Rules in Scenario 3, $P_E = 0\%$

Dependent Variable: WT5IT5OT

Tukey HSD

(I) RULE	(J) RULE	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
LPT	SPT	55.27082*	19.35126	.049	.0896	110.4520
	AR1	19.05589	19.35126	.923	-36.1253	74.2371
	AR2	41.73909	19.35126	.259	-13.4421	96.9203
	AR3	16.52489	19.35126	.957	-38.6563	71.7061
	AR4	43.38795	19.35126	.219	-11.7932	98.5691
SPT	LPT	-55.27082*	19.35126	.049	-110.4520	-.0896
	AR1	-36.21493	19.35126	.420	-91.3961	18.9663
	AR2	-13.53174	19.35126	.982	-68.7129	41.6495
	AR3	-38.74593	19.35126	.341	-93.9271	16.4353
	AR4	-11.88288	19.35126	.990	-67.0641	43.2983
AR1	LPT	-19.05589	19.35126	.923	-74.2371	36.1253
	SPT	36.21493	19.35126	.420	-18.9663	91.3961
	AR2	22.68319	19.35126	.850	-32.4980	77.8644
	AR3	-2.53100	19.35126	1.000	-57.7122	52.6502
	AR4	24.33206	19.35126	.808	-30.8491	79.5133
AR2	LPT	-41.73909	19.35126	.259	-96.9203	13.4421
	SPT	13.53174	19.35126	.982	-41.6495	68.7129
	AR1	-22.68319	19.35126	.850	-77.8644	32.4980
	AR3	-25.21420	19.35126	.784	-80.3954	29.9670
	AR4	1.64886	19.35126	1.000	-53.5323	56.8301
AR3	LPT	-16.52489	19.35126	.957	-71.7061	38.6563
	SPT	38.74593	19.35126	.341	-16.4353	93.9271
	AR1	2.53100	19.35126	1.000	-52.6502	57.7122
	AR2	25.21420	19.35126	.784	-29.9670	80.3954
	AR4	26.86306	19.35126	.734	-28.3181	82.0443
AR4	LPT	-43.38795	19.35126	.219	-98.5691	11.7932
	SPT	11.88288	19.35126	.990	-43.2983	67.0641
	AR1	-24.33206	19.35126	.808	-79.5133	30.8491
	AR2	-1.64886	19.35126	1.000	-56.8301	53.5323
	AR3	-26.86306	19.35126	.734	-82.0443	28.3181

*. The mean difference is significant at the 0.05 level.

Table B 11

Case 1: Comparison of Sequencing Rules in Scenario 3, $P_E = 0\%$

Dependent Variable: WT10IT10OT
Tukey HSD

(I) RULE	(J) RULE	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
LPT	SPT	66.01160	33.67734	.366	-30.0212	162.0444
	AR1	24.79421	33.67734	.977	-71.2386	120.8270
	AR2	49.71903	33.67734	.680	-46.3138	145.7518
	AR3	18.98483	33.67734	.993	-77.0480	115.0176
	AR4	55.68583	33.67734	.563	-40.3470	151.7186
SPT	LPT	-66.01160	33.67734	.366	-162.0444	30.0212
	AR1	-41.21739	33.67734	.825	-137.2502	54.8154
	AR2	-16.29257	33.67734	.997	-112.3254	79.7402
	AR3	-47.02677	33.67734	.729	-143.0596	49.0060
	AR4	-10.32577	33.67734	1.000	-106.3586	85.7070
AR1	LPT	-24.79421	33.67734	.977	-120.8270	71.2386
	SPT	41.21739	33.67734	.825	-54.8154	137.2502
	AR2	24.92482	33.67734	.977	-71.1080	120.9576
	AR3	-5.80938	33.67734	1.000	-101.8422	90.2234
	AR4	30.89162	33.67734	.942	-65.1412	126.9244
AR2	LPT	-49.71903	33.67734	.680	-145.7518	46.3138
	SPT	16.29257	33.67734	.997	-79.7402	112.3254
	AR1	-24.92482	33.67734	.977	-120.9576	71.1080
	AR3	-30.73420	33.67734	.943	-126.7670	65.2986
	AR4	5.96680	33.67734	1.000	-90.0660	101.9996
AR3	LPT	-18.98483	33.67734	.993	-115.0176	77.0480
	SPT	47.02677	33.67734	.729	-49.0060	143.0596
	AR1	5.80938	33.67734	1.000	-90.2234	101.8422
	AR2	30.73420	33.67734	.943	-65.2986	126.7670
	AR4	36.70100	33.67734	.886	-59.3318	132.7338
AR4	LPT	-55.68583	33.67734	.563	-151.7186	40.3470
	SPT	10.32577	33.67734	1.000	-85.7070	106.3586
	AR1	-30.89162	33.67734	.942	-126.9244	65.1412
	AR2	-5.96680	33.67734	1.000	-101.9996	90.0660
	AR3	-36.70100	33.67734	.886	-132.7338	59.3318

Table B 12

Case 1: Comparison of Sequencing Rules in Scenario 3, $P_E = 0\%$

Dependent Variable: WT15IT15OT

Tukey HSD

(I) RULE	(J) RULE	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
LPT	SPT	97.99170	47.96946	.318	-38.7959	234.7793
	AR1	34.43052	47.96946	.980	-102.3571	171.2181
	AR2	72.66342	47.96946	.655	-64.1242	209.4510
	AR3	35.02064	47.96946	.978	-101.7670	171.8082
	AR4	71.67891	47.96946	.668	-65.1087	208.4665
SPT	LPT	-97.99170	47.96946	.318	-234.7793	38.7959
	AR1	-63.56118	47.96946	.771	-200.3488	73.2264
	AR2	-25.32828	47.96946	.995	-162.1159	111.4593
	AR3	-62.97105	47.96946	.778	-199.7587	73.8165
	AR4	-26.31279	47.96946	.994	-163.1004	110.4748
AR1	LPT	-34.43052	47.96946	.980	-171.2181	102.3571
	SPT	63.56118	47.96946	.771	-73.2264	200.3488
	AR2	38.23290	47.96946	.968	-98.5547	175.0205
	AR3	.59012	47.96946	1.000	-136.1975	137.3777
	AR4	37.24839	47.96946	.972	-99.5392	174.0360
AR2	LPT	-72.66342	47.96946	.655	-209.4510	64.1242
	SPT	25.32828	47.96946	.995	-111.4593	162.1159
	AR1	-38.23290	47.96946	.968	-175.0205	98.5547
	AR3	-37.64278	47.96946	.970	-174.4304	99.1448
	AR4	-.98451	47.96946	1.000	-137.7721	135.8031
AR3	LPT	-35.02064	47.96946	.978	-171.8082	101.7670
	SPT	62.97105	47.96946	.778	-73.8165	199.7587
	AR1	-.59012	47.96946	1.000	-137.3777	136.1975
	AR2	37.64278	47.96946	.970	-99.1448	174.4304
	AR4	36.65826	47.96946	.973	-100.1293	173.4459
AR4	LPT	-71.67891	47.96946	.668	-208.4665	65.1087
	SPT	26.31279	47.96946	.994	-110.4748	163.1004
	AR1	-37.24839	47.96946	.972	-174.0360	99.5392
	AR2	.98451	47.96946	1.000	-135.8031	137.7721
	AR3	-36.65826	47.96946	.973	-173.4459	100.1293

Table B 13

Case 1: Comparison of FI and VI for Short Procedures, $P_E = 10\%$

Dependent Variable: WT5IT5OT

Tukey HSD

(I) Rule	(J) Rule	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
FI2	VI1	10.50774	49.87965	.976	-106.5118	127.5273
	VI11	19.07589	49.87965	.923	-97.9437	136.0955
VI1	FI2	-10.50774	49.87965	.976	-127.5273	106.5118
	VI11	8.56814	49.87965	.984	-108.4514	125.5877
VI11	FI2	-19.07589	49.87965	.923	-136.0955	97.9437
	VI1	-8.56814	49.87965	.984	-125.5877	108.4514

Table B 14

Case 1: Comparison of FI and VI for Short Procedures, $P_E = 10\%$

Dependent Variable: WT10IT10OT

Tukey HSD

(I) Rule	(J) Rule	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
FI3	VI2	15.91156	85.37868	.981	-184.3901	216.2132
	VI10	27.04520	85.37868	.946	-173.2565	227.3469
VI2	FI3	-15.91156	85.37868	.981	-216.2132	184.3901
	VI10	11.13364	85.37868	.991	-189.1680	211.4353
VI10	FI3	-27.04520	85.37868	.946	-227.3469	173.2565
	VI2	-11.13364	85.37868	.991	-211.4353	189.1680

Table B 15

Case 1: Comparison of FI and VI for Short Procedures, $P_E = 10\%$

Dependent Variable: WT15IT15OT

Tukey HSD

(I) Rule	(J) Rule	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
FI4	VI4	22.05626	121.05727	.982	-261.9488	306.0613
	VI10	39.89185	121.05727	.942	-244.1132	323.8969
VI4	FI4	-22.05626	121.05727	.982	-306.0613	261.9488
	VI10	17.83559	121.05727	.988	-266.1694	301.8406
VI10	FI4	-39.89185	121.05727	.942	-323.8969	244.1132
	VI4	-17.83559	121.05727	.988	-301.8406	266.1694

Table B 16

Case 1: Comparison of FI and VI for Long Procedures, $P_E = 10\%$

T-Test

Group Statistics

	Rule	N	Mean	Std. Deviation	Std. Error Mean
WT5IT 5OT	FI7	500	418.8584	496.82605	22.21874
	VI18	500	427.6589	494.20885	22.10169

Independent Samples Test

		Levene's Test for Equality of Variances	
		F	Sig.
WT5IT 5OT	Equal variances assumed	.035	.851
	Equal variances not assumed		

Independent Samples Test

		t-test for Equality of Means			
		t	df	Sig. (2-tailed)	Mean Difference
WT5IT 5OT	Equal variances assumed	-.281	998	.779	-8.80042
	Equal variances not assumed	-.281	997.972	.779	-8.80042

Independent Samples Test

		t-test for Equality of Means		
		Std. Error Difference	95% Confidence Interval of the Difference	
			Lower	Upper
WT5IT 5OT	Equal variances assumed	31.33938	-70.29907	52.69823
	Equal variances not assumed	31.33938	-70.29907	52.69823

Table B 17

Case 1: Comparison of FI and VI for Long Procedures, $P_E = 10\%$

T-Test

Group Statistics

	Rule	N	Mean	Std. Deviation	Std. Error Mean
WT10IT	FI9	500	707.8219	920.87933	41.18298
10OT	VI18	500	707.7721	923.62901	41.30595

Independent Samples Test

		Levene's Test for Equality of Variances	
		F	Sig.
WT10IT	Equal variances assumed	.011	.918
10OT	Equal variances not assumed		

Independent Samples Test

		t-test for Equality of Means			
		t	df	Sig. (2-tailed)	Mean Difference
WT10IT	Equal variances assumed	.001	998	.999	.04987
10OT	Equal variances not assumed	.001	997.991	.999	.04987

Independent Samples Test

		t-test for Equality of Means		
		Std. Error Difference	95% Confidence Interval of the Difference	
			Lower	Upper
WT10IT	Equal variances assumed	58.32854	-114.41078	114.51052
10OT	Equal variances not assumed	58.32854	-114.41078	114.51052

Table B 18

Case 1: Comparison of FI and VI for Long Procedures, $P_E = 10\%$

T-Test

Group Statistics

	Rule	N	Mean	Std. Deviation	Std. Error Mean
WT15IT 15OT	FI9	500	993.2438	1356.32002	60.65648
	VI18	500	987.8854	1355.13984	60.60370

Independent Samples Test

		Levene's Test for Equality of Variances	
		F	Sig.
WT15IT 15OT	Equal variances assumed	.001	.977
	Equal variances not assumed		

Independent Samples Test

		t-test for Equality of Means			
		t	df	Sig. (2-tailed)	Mean Difference
WT15IT 15OT	Equal variances assumed	.062	998	.950	5.35850
	Equal variances not assumed	.062	997.999	.950	5.35850

Independent Samples Test

		t-test for Equality of Means		
		Std. Error Difference	95% Confidence Interval of the Difference	
			Lower	Upper
WT15IT 15OT	Equal variances assumed	85.74390	-162.90051	173.61751
	Equal variances not assumed	85.74390	-162.90051	173.61751

Table B 19

Case 1: Comparison of Sequencing Rules in Scenario 2, $P_E = 10\%$

Dependent Variable: WT5IT5OT

Tukey HSD

(I) RULE	(J) RULE	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
LPT	SPT	37.96421	39.79053	.606	-55.3859	131.3143
	AR3	1.21375	39.79053	.999	-92.1364	94.5639
SPT	LPT	-37.96421	39.79053	.606	-131.3143	55.3859
	AR3	-36.75045	39.79053	.625	-130.1006	56.5997
AR3	LPT	-1.21375	39.79053	.999	-94.5639	92.1364
	SPT	36.75045	39.79053	.625	-56.5997	130.1006

Table B 20

Case 1: Comparison of Sequencing Rules in Scenario 2, $P_E = 10\%$

Dependent Variable: WT10IT10OT

Tukey HSD

(I) RULE	(J) RULE	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
LPT	SPT	48.31093	70.55434	.772	-117.2123	213.8341
	AR3	-.37727	70.55434	1.000	-165.9005	165.1459
SPT	LPT	-48.31093	70.55434	.772	-213.8341	117.2123
	AR3	-48.68820	70.55434	.769	-214.2114	116.8350
AR3	LPT	.37727	70.55434	1.000	-165.1459	165.9005
	SPT	48.68820	70.55434	.769	-116.8350	214.2114

Table B 21

Case 1: Comparison of Sequencing Rules in Scenario 2, $P_E = 10\%$

Dependent Variable: WT15IT15OT

Tukey HSD

(I) RULE	(J) RULE	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
LPT	SPT	82.12331	101.56768	.698	-156.1584	320.4050
	AR3	18.62495	101.56768	.982	-219.6567	256.9066
SPT	LPT	-82.12331	101.56768	.698	-320.4050	156.1584
	AR3	-63.49835	101.56768	.806	-301.7800	174.7833
AR3	LPT	-18.62495	101.56768	.982	-256.9066	219.6567
	SPT	63.49835	101.56768	.806	-174.7833	301.7800

Table B 22

Case 1: Comparison of Sequencing Rules in Scenario 3, $P_E = 10\%$

Dependent Variable: WT5IT5OT

Tukey HSD

(I) RULE	(J) RULE	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
LPT	SPT	53.52681	36.36590	.682	-50.1726	157.2262
	AR1	17.37100	36.36590	.997	-86.3284	121.0704
	AR2	41.59324	36.36590	.863	-62.1061	145.2926
	AR3	14.01290	36.36590	.999	-89.6865	117.7123
	AR4	43.83372	36.36590	.834	-59.8657	147.5331
SPT	LPT	-53.52681	36.36590	.682	-157.2262	50.1726
	AR1	-36.15582	36.36590	.920	-139.8552	67.5436
	AR2	-11.93357	36.36590	.999	-115.6330	91.7658
	AR3	-39.51391	36.36590	.887	-143.2133	64.1855
	AR4	-9.69309	36.36590	1.000	-113.3925	94.0063
AR1	LPT	-17.37100	36.36590	.997	-121.0704	86.3284
	SPT	36.15582	36.36590	.920	-67.5436	139.8552
	AR2	24.22224	36.36590	.986	-79.4771	127.9216
	AR3	-3.35809	36.36590	1.000	-107.0575	100.3413
	AR4	26.46273	36.36590	.979	-77.2367	130.1621
AR2	LPT	-41.59324	36.36590	.863	-145.2926	62.1061
	SPT	11.93357	36.36590	.999	-91.7658	115.6330
	AR1	-24.22224	36.36590	.986	-127.9216	79.4771
	AR3	-27.58034	36.36590	.974	-131.2797	76.1190
	AR4	2.24048	36.36590	1.000	-101.4589	105.9399
AR3	LPT	-14.01290	36.36590	.999	-117.7123	89.6865
	SPT	39.51391	36.36590	.887	-64.1855	143.2133
	AR1	3.35809	36.36590	1.000	-100.3413	107.0575
	AR2	27.58034	36.36590	.974	-76.1190	131.2797
	AR4	29.82082	36.36590	.964	-73.8786	133.5202
AR4	LPT	-43.83372	36.36590	.834	-147.5331	59.8657
	SPT	9.69309	36.36590	1.000	-94.0063	113.3925
	AR1	-26.46273	36.36590	.979	-130.1621	77.2367
	AR2	-2.24048	36.36590	1.000	-105.9399	101.4589
	AR3	-29.82082	36.36590	.964	-133.5202	73.8786

Table B 23

Case 1: Comparison of Sequencing Rules in Scenario 3, $P_E = 10\%$

Dependent Variable: WT10IT10OT

Tukey HSD

(I) RULE	(J) RULE	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
LPT	SPT	64.05612	65.85129	.927	-123.7225	251.8347
	AR1	22.15272	65.85129	.999	-165.6259	209.9313
	AR2	50.60456	65.85129	.973	-137.1740	238.3832
	AR3	17.88337	65.85129	1.000	-169.8952	205.6620
	AR4	54.92146	65.85129	.961	-132.8572	242.7001
SPT	LPT	-64.05612	65.85129	.927	-251.8347	123.7225
	AR1	-41.90340	65.85129	.988	-229.6820	145.8752
	AR2	-13.45156	65.85129	1.000	-201.2302	174.3271
	AR3	-46.17275	65.85129	.982	-233.9514	141.6059
	AR4	-9.13466	65.85129	1.000	-196.9133	178.6439
AR1	LPT	-22.15272	65.85129	.999	-209.9313	165.6259
	SPT	41.90340	65.85129	.988	-145.8752	229.6820
	AR2	28.45184	65.85129	.998	-159.3268	216.2305
	AR3	-4.26935	65.85129	1.000	-192.0480	183.5093
	AR4	32.76873	65.85129	.996	-155.0099	220.5473
AR2	LPT	-50.60456	65.85129	.973	-238.3832	137.1740
	SPT	13.45156	65.85129	1.000	-174.3271	201.2302
	AR1	-28.45184	65.85129	.998	-216.2305	159.3268
	AR3	-32.72120	65.85129	.996	-220.4998	155.0574
	AR4	4.31689	65.85129	1.000	-183.4617	192.0955
AR3	LPT	-17.88337	65.85129	1.000	-205.6620	169.8952
	SPT	46.17275	65.85129	.982	-141.6059	233.9514
	AR1	4.26935	65.85129	1.000	-183.5093	192.0480
	AR2	32.72120	65.85129	.996	-155.0574	220.4998
	AR4	37.03809	65.85129	.993	-150.7405	224.8167
AR4	LPT	-54.92146	65.85129	.961	-242.7001	132.8572
	SPT	9.13466	65.85129	1.000	-178.6439	196.9133
	AR1	-32.76873	65.85129	.996	-220.5473	155.0099
	AR2	-4.31689	65.85129	1.000	-192.0955	183.4617
	AR3	-37.03809	65.85129	.993	-224.8167	150.7405

Table B 24

Case 1: Comparison of Sequencing Rules in Scenario 3, $P_E = 10\%$

Dependent Variable: WT15IT15OT

Tukey HSD

(I) RULE	(J) RULE	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
LPT	SPT	94.10889	95.42208	.922	-177.9925	366.2103
	AR1	31.09364	95.42208	1.000	-241.0077	303.1950
	AR2	72.84288	95.42208	.974	-199.2585	344.9442
	AR3	30.79847	95.42208	1.000	-241.3029	302.8998
	AR4	72.99925	95.42208	.973	-199.1021	345.1006
SPT	LPT	-94.10889	95.42208	.922	-366.2103	177.9925
	AR1	-63.01525	95.42208	.986	-335.1166	209.0861
	AR2	-21.26601	95.42208	1.000	-293.3674	250.8354
	AR3	-63.31042	95.42208	.986	-335.4118	208.7909
	AR4	-21.10964	95.42208	1.000	-293.2110	250.9917
AR1	LPT	-31.09364	95.42208	1.000	-303.1950	241.0077
	SPT	63.01525	95.42208	.986	-209.0861	335.1166
	AR2	41.74924	95.42208	.998	-230.3521	313.8506
	AR3	-.29517	95.42208	1.000	-272.3965	271.8062
	AR4	41.90561	95.42208	.998	-230.1958	314.0070
AR2	LPT	-72.84288	95.42208	.974	-344.9442	199.2585
	SPT	21.26601	95.42208	1.000	-250.8354	293.3674
	AR1	-41.74924	95.42208	.998	-313.8506	230.3521
	AR3	-42.04441	95.42208	.998	-314.1458	230.0570
	AR4	.15638	95.42208	1.000	-271.9450	272.2577
AR3	LPT	-30.79847	95.42208	1.000	-302.8998	241.3029
	SPT	63.31042	95.42208	.986	-208.7909	335.4118
	AR1	.29517	95.42208	1.000	-271.8062	272.3965
	AR2	42.04441	95.42208	.998	-230.0570	314.1458
	AR4	42.20079	95.42208	.998	-229.9006	314.3022
AR4	LPT	-72.99925	95.42208	.973	-345.1006	199.1021
	SPT	21.10964	95.42208	1.000	-250.9917	293.2110
	AR1	-41.90561	95.42208	.998	-314.0070	230.1958
	AR2	-.15638	95.42208	1.000	-272.2577	271.9450
	AR3	-42.20079	95.42208	.998	-314.3022	229.9006

Appendix C Simulation Results of Case 2

Table C 1

Case 2: FI and VI for Short Procedures, $P_E = 0\%$

	Fixed Interval Rule					Dome Rule			Increasing Interval Rule		
	FI 1	**FI 2**	**FI 3**	**FI 4**	**FI 5**	**VI 1**	**VI 2**	**VI 3**	**VI 4**	**VI 5**	**VI 6**
Performance Measure	**Average, 95% C.I.**										
Total Waiting Time (min)	213.25 ± 20.69	301.09 ± 24.28	418.69 ± 27.07	563.21 ± 28.79	727.79 ± 29.48	206.74 ± 20.7	298.68 ± 24.64	425.69 ± 27.82	345.16 ± 26.22	493.55 ± 28.67	666.03 ± 29.5
Total Idle Time (min)	38.83 ± 2.68	19.66 ± 1.74	8.07 ± 0.92	2.43 ± 0.36	0.28 ± 0.07	36.34 ± 2.88	16.47 ± 1.87	4.66 ± 0.89	17.2 ± 2.24	4.71 ± 1.03	0.35 ± 0.21
Overtime (min)	38.91 ± 4.07	30.54 ± 3.98	27.39 ± 3.86	25.67 ± 3.78	24.9 ± 3.74	36.5 ± 3.91	27.97 ± 3.84	25.42 ± 3.76	26.29 ± 3.76	24.87 ± 3.73	24.79 ± 3.73
Utilization	0.92 ± 0.01	0.96 ± 0	0.98 ± 0	0.99 ± 0	1 ± 0	0.93 ± 0.01	0.96 ± 0	0.99 ± 0	0.96 ± 0	0.99 ± 0	1 ± 0
WTITOT	290.99 ± 22.62	351.29 ± 26.79	454.15 ± 29.89	591.31 ± 31.73	752.98 ± 32.44	279.58 ± 22.22	343.12 ± 26.83	455.77 ± 30.48	388.65 ± 28.02	523.13 ± 31.21	691.16 ± 32.42
WT5IT5OT	601.97 ± 34.17	552.09 ± 39.19	595.99 ± 42.78	703.69 ± 44.73	853.72 ± 45.44	570.96 ± 32.68	520.87 ± 38.13	576.09 ± 42.7	562.59 ± 38.03	641.45 ± 42.96	791.7 ± 45.29
WT10IT10OT	990.7 ± 52.08	803.1 ± 57	773.29 ± 60.52	844.17 ± 62.3	979.65 ± 62.93	935.18 ± 49.94	743.06 ± 54.81	726.49 ± 59.61	780.02 ± 53.65	789.36 ± 59.42	917.37 ± 62.64
WT15IT15OT	1379.43 ± 71.17	1054.1 ± 75.69	950.59 ± 78.93	984.65 ± 80.45	1105.58 ± 80.95	1299.4 ± 68.61	965.25 ± 72.5	876.9 ± 77.23	997.45 ± 70.6	937.27 ± 76.67	1043.04 ± 80.56
WT20IT20OT	1768.15 ± 90.68	1305.11 ± 94.74	1127.89 ± 97.64	1125.13 ± 98.86	1231.51 ± 99.23	1663.62 ± 87.79	1187.44 ± 90.62	1027.3 ± 95.16	1214.88 ± 88.11	1085.17 ± 94.27	1168.71 ± 98.73

Table C 2

Case 2: FI and VI for Long Procedures, $P_E = 0\%$

	Fixed Interval Rule								**Increasing Interval Rule**					
	FI 1	**FI 3**	**FI 5**	**FI 7**	**FI 9**	**FI 11**	**FI 13**	**FI 15**	**VI 7**	**VI 8**	**VI 9**	**VI 10**	**VI 11**	**VI 12**
Performance Measure	**Average, 95% C.I.**													
Total Waiting Time (min)	57.11 ± 6.11	72.37 ± 6.9	90.03 ± 7.65	110.45 ± 8.31	132.94 ± 8.89	157.09 ± 9.41	182.69 ± 9.85	209.57 ±10.19	102.15 ± 8.15	124.22 ± 8.76	147.99 ± 9.3	173.25 ± 9.77	199.88 ±10.14	227.95 ±10.38
Total Idle Time (min)	37.82 ± 3.79	28.23 ± 3.25	20.34 ± 2.72	14.32 ± 2.19	9.66 ± 1.69	6.07 ± 1.24	3.45 ± 0.83	1.62 ± 0.5	16.02 ± 2.4	10.94 ± 1.88	6.96 ± 1.39	4.02 ± 0.95	1.93 ± 0.58	0.75 ± 0.29
Overtime (min)	38.82 ± 4.54	35.29 ± 4.48	32.84 ± 4.45	31.34 ± 4.42	30.44 ± 4.41	29.91 ± 4.4	29.6 ± 4.39	29.45 ± 4.39	31.52 ± 4.42	30.49 ± 4.4	29.93 ± 4.4	29.6 ± 4.39	29.45 ± 4.39	29.39 ± 4.39
Utilization	0.92 ± 0.01	0.94 ± 0.01	0.95 ± 0.01	0.97 ± 0.01	0.98 ± 0	0.98 ± 0	0.99 ± 0	1 ± 0	0.96 ± 0.01	0.97 ± 0	0.98 ± 0	0.99 ± 0	0.99 ± 0	1 ± 0
WITOT	133.75 ± 8.57	135.89 ± 9.4	143.21 ± 10.25	156.11 ± 11.01	173.03 ±11.72	193.07 ±12.37	215.75 ±12.94	240.63 ±13.39	149.69 ± 10.78	165.65 ±11.51	184.88 ±12.21	206.87 ±12.82	231.25 ±13.32	258.09 ±13.64
WT5IT5OT	440.33 ± 26.73	389.96 ± 26.47	355.94 ± 26.57	338.76 ± 26.82	333.4 ±27.28	336.99 ±27.94	347.97 ±28.64	364.89 ± 29.3	339.83 ± 26.65	331.37 ±27.06	332.44 ±27.72	341.36 ±28.46	356.74 ±29.18	378.64 ±29.66
WT10IT10OT	823.55 ± 51.32	707.56 ± 49.77	621.84 ± 48.87	567.07 ± 48.39	533.86 ±48.42	516.89 ±48.97	513.25 ±49.72	520.2 ±50.55	577.52 ± 48.37	538.53 ±48.25	516.9 ±48.72	509.46 ±49.51	513.59 ±50.39	529.34 ±51.02
WT15IT15OT	1206.78 ± 76.12	1025.15 ± 73.32	887.74 ± 71.46	795.37 ± 70.26	734.33 ±69.85	696.79 ±70.28	678.53 ±71.08	675.51 ±72.06	815.2 ± 70.4	745.68 ±69.75	701.36 ±70.03	677.56 ±70.84	670.45 ±71.87	680.03 ±72.64
WT20IT20OT	1590 ±100.98	1342.75 ± 96.94	1153.64 ± 94.12	1023.68 ± 92.21	934.79 ±91.38	876.69 ±91.68	843.81 ±92.52	830.83 ±93.67	1052.88 ± 92.51	952.84 ±91.34	885.81 ±91.42	845.66 ±92.26	827.31 ±93.45	830.73 ±94.34

Table C 3

Case 2: FI and VI for Short Procedures, $P_E = 10\%$

	Fixed Interval Rule					**Dome Rule**			**Increasing Interval Rule**		
	FI 1	**FI 2**	**FI 3**	**FI 4**	**FI 5**	**VI 1**	**VI 2**	**VI 3**	**VI 4**	**VI 5**	**VI 6**
Performance Measure	**Average, 95% C.I.**										
Total Waiting Time (min)	492.3 ± 45.99	580.94 ± 47.3	688.04 ± 48.08	807.94 ± 48.05	935.19 ± 45.8	488.54 ± 46.84	583.61 ± 47.82	698 ± 48.22	624.12 ± 47.39	753.44 ± 46.47	890.19 ± 44.23
Total Idle Time (min)	27.33 ± 2.36	14.06 ± 1.46	6.08 ± 0.77	1.91 ± 0.3	0.23 ± 0.06	23.52 ± 2.5	10.24 ± 1.51	2.63 ± 0.67	8.91 ± 1.65	2.08 ± 0.67	0.07 ± 0.08
Overtime (min)	115.97 ± 11.27	109.53 ± 11.48	106.69 ± 11.5	104.46 ± 11.44	103.46 ± 11.41	115.29 ± 11.44	107.14 ± 11.5	104.12 ± 11.43	105.06 ± 11.42	103.49 ± 11.42	103.3 ± 11.41
Utilization	1.0 ± 0	1.0 ± 0	1.0 ± 0	1.0 ± 0	1.0 ± 0	1.0 ± 0	1.0 ± 0	1.0 ± 0	1.0 ± 0	1.0 ± 0	1.0 ± 0
WTITOT	635.6 ± 53.37	704.53 ± 55.52	800.81 ± 56.29	914.3 ± 55.92	1038.89 ± 53.32	627.34 ± 54.59	700.99 ± 56.05	804.75 ± 56.48	738.08 ± 55.37	859.01 ± 54.81	993.57 ± 52.34
WT5IT5OT	1208.81 ± 90.36	1198.88 ± 94.91	1251.87 ± 95.95	1339.78 ± 94.91	1453.65 ± 91.8	1182.58 ± 92.45	1170.51 ± 95.36	1231.75 ± 96.03	1193.94 ± 93.74	1281.28 ± 94.57	1407.06 ± 92.05
WT10IT10OT	1925.31 ± 142.03	1816.83 ± 148.83	1815.71 ± 150.42	1871.62 ± 149.07	1972.11 ± 145.83	1876.62 ± 144.77	1757.4 ± 149.11	1765.5 ± 150.14	1763.76 ± 146.38	1809.13 ± 148.72	1923.92 ± 146.62
WT15IT15OT	2641.81 ± 195.29	2434.77 ± 204.12	2379.54 ± 206.34	2403.46 ± 204.82	2490.57 ± 201.53	2570.66 ± 198.57	2344.3 ± 204.21	2299.25 ± 205.64	2333.59 ± 200.41	2336.98 ± 204.17	2440.79 ± 202.56
WT20IT20OT	3358.31 ± 249.12	3052.71 ± 259.9	2943.37 ± 262.78	2935.3 ± 261.14	3009.03 ± 257.83	3264.7 ± 252.89	2931.19 ± 259.82	2833.01 ± 261.64	2903.41 ± 254.95	2864.82 ± 260.08	2957.65 ± 258.98

Table C 4

Case 2: FI and VI for Long Procedures, $P_E = 10\%$

	Fixed Interval Rule								Increasing Interval Rule					
	FI 1	**FI 3**	**FI 5**	**FI 7**	**FI 9**	**FI 11**	**FI 13**	**FI 15**	**VI 7**	**VI 8**	**VI 9**	**VI 10**	**VI 11**	**VI 12**
Performance Measure	**Average, 95% C.I.**													
Total Waiting Time (min)	76.00 ± 8.96	90.07 ± 9.03	107.99 ± 9.56	126.72 ± 9.89	149.29 ± 10.32	171.15 ± 10.41	195.37 ± 10.67	219.11 ± 10.58	118.59 ± 9.77	140.77 ± 10.29	163.72 ± 10.63	187.02 ± 10.68	210.61 ± 10.45	235.82 ± 10.62
Total Idle Time (min)	32.4 ± 3.59	24.12 ± 3.05	17.37 ± 2.53	12.18 ± 2.03	8.2 ± 1.56	5.15 ± 1.14	2.94 ± .78	1.42 ± 0.47	13.54 ± 2.21	9.19 ± 1.72	5.83 ± 1.27	3.34 ± 0.88	1.63 ± 0.55	0.66 ± 0.28
Overtime (min)	63.52 ± 7.52	60.03 ± 7.49	57.51 ± 7.47	55.85 ± 7.45	54.71 ± 7.43	54.01 ± 7.4	53.54 ± 7.38	53.21 ± 7.37	56.1 ± 7.45	54.84 ± 7.42	54.06 ± 7.4	53.58 ± 7.38	53.23 ± 7.37	53.06 ± 7.37
Utilization	1.0 ± 0	1.0 ± 0	1.0 ± 0	1.0 ± 0	1.0 ± 0	1.0 ± 0	1.0 ± 0	1.0 ± 0	1.0 ± 0	1.0 ± 0	1.0 ± 0	1.0 ± 0	1.0 ± 0	1.0 ± 0
WITOT	171.93 ± 13.98	174.22 ± 14.1	182.87 ± 14.73	194.75 ± 15.16	212.2 ± 15.64	230.3 ± 15.71	251.85 ± 16.02	273.75 ± 15.9	188.23 ± 15.02	204.79 ± 15.58	223.6 ± 16	243.94 ± 16.04	265.48 ± 15.77	289.55 ± 15.9
WT5IT5OT	555.63 ± 42.16	510.81 ± 42.01	482.36 ± 42.48	466.86 ± 42.83	463.85 ± 43.21	466.94 ± 43.21	477.77 ± 43.55	492.3 ± 43.45	466.79 ± 42.67	460.9 ± 43.1	463.14 ± 43.51	471.65 ± 43.55	484.93 ± 43.34	504.45 ± 43.5
WT10IT10OT	1035.26 ± 79.23	931.55 ± 78.68	856.72 ± 78.95	807.00 ± 79.13	778.41 ± 79.38	762.73 ± 79.33	760.18 ± 79.70	765.48 ± 79.66	814.99 ± 78.93	781.03 ± 79.22	762.56 ± 79.58	756.28 ± 79.67	759.25 ± 79.54	773.07 ± 79.79
WT15IT15OT	1514.89 ±116.53	1352.29 ±115.57	1231.09 ±115.66	1147.15 ±115.67	1092.96 ± 115.8	1058.52 ±115.71	1042.59 ±116.10	1038.67 ±116.12	1163.2 ±115.43	1101.17 ±115.59	1061.98 ±115.91	1040.91 ±116.05	1033.58 ±115.99	1041.7 ±116.35
WT20IT20OT	1994.53 ± 153.9	1773.03 ±152.53	1605.45 ±152.43	1487.29 ±152.27	1407.52 ±152.29	1354.31 ±152.15	1325 ±152.57	1311.85 ±152.66	1511.4 ± 152	1421.3 ±152.03	1361.41 ±152.3	1325.54 ±152.49	1307.89 ±152.51	1310.32 ±152.98

Appendix D ANOVA Results of Case 2

Table D 1

Case 2: Comparison of FI and VI for Short Procedures, $P_E = 0\%$

Dependent Variable: WT5IT5OT
Tukey HSD

(I) Rule	(J) Rule	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
FI2	VI2	31.22335	27.60432	.495	-33.5374	95.9841
	VI4	-10.50010	27.60432	.923	-75.2609	54.2607
VI2	FI2	-31.22335	27.60432	.495	-95.9841	33.5374
	VI4	-41.72345	27.60432	.286	-106.4842	23.0373
VI4	FI2	10.50010	27.60432	.923	-54.2607	75.2609
	VI2	41.72345	27.60432	.286	-23.0373	106.4842

Table D 2

Case 2: Comparison of FI and VI for Short Procedures, $P_E = 0\%$

Dependent Variable: WT10IT10OT
Tukey HSD

(I) Rule	(J) Rule	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
FI3	VI3	46.79543	41.64265	.500	-50.8998	144.4907
	VI4	-6.73248	41.64265	.986	-104.4277	90.9628
VI3	FI3	-46.79543	41.64265	.500	-144.4907	50.8998
	VI4	-53.52792	41.64265	.404	-151.2232	44.1673
VI4	FI3	6.73248	41.64265	.986	-90.9628	104.4277
	VI3	53.52792	41.64265	.404	-44.1673	151.2232

Table D 3

Case 2: Comparison of FI and VI for Short Procedures, $P_E = 0\%$

Dependent Variable: WT15IT15OT
Tukey HSD

(I) Rule	(J) Rule	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
FI3	VI3	73.69479	55.71867	.383	-57.0234	204.4129
	VI5	13.32508	55.71867	.969	-117.3931	144.0432
VI3	FI3	-73.69479	55.71867	.383	-204.4129	57.0234
	VI5	-60.36971	55.71867	.524	-191.0879	70.3484
VI5	FI3	-13.32508	55.71867	.969	-144.0432	117.3931
	VI3	60.36971	55.71867	.524	-70.3484	191.0879

Table D 4

Case 2: Comparison of FI and VI for Long Procedures, $P_E = 0\%$

T-Test

Group Statistics

	Rule	N	Mean	Std. Deviation	Std. Error Mean
WT5IT	FI9	500	333.4014	309.63645	13.84736
5OT	VI 8	500	331.3736	307.16294	13.73674

Independent Samples Test

		Levene's Test for Equality of Variances	
		F	Sig.
WT5IT	Equal variances assumed	.013	.911
5OT	Equal variances not assumed		

Independent Samples Test

		t-test for Equality of Means			
		t	df	Sig. (2-tailed)	Mean Difference
WT5IT	Equal variances assumed	.104	998	.917	2.02779
5OT	Equal variances not assumed	.104	997.936	.917	2.02779

Independent Samples Test

		t-test for Equality of Means		
		Std. Error Difference	95% Confidence Interval of the Difference	
			Lower	Upper
WT5IT	Equal variances assumed	19.50507	-36.24785	40.30344
5OT	Equal variances not assumed	19.50507	-36.24786	40.30344

Table D 5

Case 2: Comparison of FI and VI for Long Procedures, $P_E = 0\%$

T-Test

Group Statistics

	Rule	N	Mean	Std. Deviation	Std. Error Mean
WT10IT 10OT	FI13	500	513.2489	564.32275	25.23728
	VI10	500	509.4566	561.93928	25.13069

Independent Samples Test

		Levene's Test for Equality of Variances	
		F	Sig.
WT10IT 10OT	Equal variances assumed	.008	.931
	Equal variances not assumed		

Independent Samples Test

		t-test for Equality of Means			
		t	df	Sig. (2-tailed)	Mean Difference
WT10IT 10OT	Equal variances assumed	.106	998	.915	3.79231
	Equal variances not assumed	.106	997.982	.915	3.79231

Independent Samples Test

		t-test for Equality of Means		
		Std. Error Difference	95% Confidence Interval of the Difference	
			Lower	Upper
WT10IT 10OT	Equal variances assumed	35.61561	-66.09777	73.68239
	Equal variances not assumed	35.61561	-66.09777	73.68239

Table D 6

Case 2: Comparison of FI and VI for Long Procedures, $P_E = 0\%$

T-Test

Group Statistics

	Rule	N	Mean	Std. Deviation	Std. Error Mean
WT15IT15OT	FI15	500	675.5144	817.97054	36.58075
	VI11	500	670.4522	815.81193	36.48422

Independent Samples Test

		Levene's Test for Equality of Variances	
		F	Sig.
WT15IT15OT	Equal variances assumed	.006	.937
	Equal variances not assumed		

Independent Samples Test

		t-test for Equality of Means			
		t	df	Sig. (2-tailed)	Mean Difference
WT15IT15OT	Equal variances assumed	.098	998	.922	5.06218
	Equal variances not assumed	.098	997.993	.922	5.06218

Independent Samples Test

		t-test for Equality of Means		
		Std. Error Difference	95% Confidence Interval of the Difference	
			Lower	Upper
WT15IT15OT	Equal variances assumed	51.66478	-96.32189	106.44625
	Equal variances not assumed	51.66478	-96.32189	106.44625

Table D 7

Case 2: Comparison of Sequencing Rules in Scenario 2, $P_E = 0\%$

Dependent Variable: WT5IT5OT

Tukey HSD

(I) RULE	(J) RULE	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
LPT	SPT	151.04278*	26.78768	.000	88.1978	213.8877
	AR3	40.74982	26.78768	.281	-22.0951	103.5948
SPT	LPT	-151.04278*	26.78768	.000	-213.8877	-88.1978
	AR3	-110.29296*	26.78768	.000	-173.1379	-47.4480
AR3	LPT	-40.74982	26.78768	.281	-103.5948	22.0951
	SPT	110.29296*	26.78768	.000	47.4480	173.1379

*. The mean difference is significant at the 0.05 level.

Table D 8

Case 2: Comparison of Sequencing Rules in Scenario 2, $P_E = 0\%$

Dependent Variable: WT10IT10OT

Tukey HSD

(I) RULE	(J) RULE	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
LPT	SPT	235.42507*	43.31176	.000	133.8140	337.0361
	AR3	81.86738	43.31176	.142	-19.7437	183.4784
SPT	LPT	-235.42507*	43.31176	.000	-337.0361	-133.8140
	AR3	-153.55769*	43.31176	.001	-255.1688	-51.9466
AR3	LPT	-81.86738	43.31176	.142	-183.4784	19.7437
	SPT	153.55769*	43.31176	.001	51.9466	255.1688

*. The mean difference is significant at the 0.05 level.

Table D 9

Case 2: Comparison of Sequencing Rules in Scenario 2, $P_E = 0\%$

Dependent Variable: WT15IT15OT

Tukey HSD

(I) RULE	(J) RULE	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
LPT	SPT	229.01761*	58.49073	.000	91.7961	366.2391
	AR3	59.22254	58.49073	.569	-77.9990	196.4441
SPT	LPT	-229.01761*	58.49073	.000	-366.2391	-91.7961
	AR3	-169.79507*	58.49073	.010	-307.0166	-32.5736
AR3	LPT	-59.22254	58.49073	.569	-196.4441	77.9990
	SPT	169.79507*	58.49073	.010	32.5736	307.0166

*. The mean difference is significant at the 0.05 level.

Table D 10

Case 2: Comparison of Sequencing Rules in Scenario 3, $P_E = 0\%$

Dependent Variable: WT5IT5OT
Tukey HSD

(I) Rule	(J) Rule	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
LPT	SPT	150.58363*	23.21096	.000	84.3963	216.7710
	AR1	31.40268	23.21096	.755	-34.7847	97.5900
	AR2	65.65595	23.21096	.053	-.5314	131.8433
	AR3	85.95934*	23.21096	.003	19.7720	152.1467
	AR4	100.60635*	23.21096	.000	34.4190	166.7937
SPT	LPT	-150.58363*	23.21096	.000	-216.7710	-84.3963
	AR1	-119.18095*	23.21096	.000	-185.3683	-52.9936
	AR2	-84.92768*	23.21096	.004	-151.1150	-18.7403
	AR3	-64.62428	23.21096	.060	-130.8116	1.5631
	AR4	-49.97728	23.21096	.260	-116.1646	16.2101
AR1	LPT	-31.40268	23.21096	.755	-97.5900	34.7847
	SPT	119.18095*	23.21096	.000	52.9936	185.3683
	AR2	34.25328	23.21096	.680	-31.9341	100.4406
	AR3	54.55667	23.21096	.174	-11.6307	120.7440
	AR4	69.20367*	23.21096	.034	3.0163	135.3910
AR2	LPT	-65.65595	23.21096	.053	-131.8433	.5314
	SPT	84.92768*	23.21096	.004	18.7403	151.1150
	AR1	-34.25328	23.21096	.680	-100.4406	31.9341
	AR3	20.30339	23.21096	.953	-45.8840	86.4908
	AR4	34.95040	23.21096	.661	-31.2370	101.1378
AR3	LPT	-85.95934*	23.21096	.003	-152.1467	-19.7720
	SPT	64.62428	23.21096	.060	-1.5631	130.8116
	AR1	-54.55667	23.21096	.174	-120.7440	11.6307
	AR2	-20.30339	23.21096	.953	-86.4908	45.8840
	AR4	14.64701	23.21096	.989	-51.5404	80.8344
AR4	LPT	-100.60635*	23.21096	.000	-166.7937	-34.4190
	SPT	49.97728	23.21096	.260	-16.2101	116.1646
	AR1	-69.20367*	23.21096	.034	-135.3910	-3.0163
	AR2	-34.95040	23.21096	.661	-101.1378	31.2370
	AR3	-14.64701	23.21096	.989	-80.8344	51.5404

*. The mean difference is significant at the 0.05 level.

Table D 11

Case 2: Comparison of Sequencing Rules in Scenario 3, $P_E = 0\%$

Dependent Variable: WT10IT10OT
Tukey HSD

(I) Rule	(J) Rule	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
LPT	SPT	232.37186*	39.21181	.000	120.5572	344.1865
	AR1	47.52284	39.21181	.831	-64.2918	159.3375
	AR2	105.96349	39.21181	.075	-5.8512	217.7782
	AR3	140.50056*	39.21181	.005	28.6859	252.3152
	AR4	143.00081*	39.21181	.004	31.1862	254.8155
SPT	LPT	-232.37186*	39.21181	.000	-344.1865	-120.5572
	AR1	-184.84902*	39.21181	.000	-296.6637	-73.0344
	AR2	-126.40837*	39.21181	.016	-238.2230	-14.5937
	AR3	-91.87131	39.21181	.177	-203.6860	19.9434
	AR4	-89.37105	39.21181	.203	-201.1857	22.4436
AR1	LPT	-47.52284	39.21181	.831	-159.3375	64.2918
	SPT	184.84902*	39.21181	.000	73.0344	296.6637
	AR2	58.44065	39.21181	.671	-53.3740	170.2553
	AR3	92.97772	39.21181	.167	-18.8369	204.7924
	AR4	95.47797	39.21181	.145	-16.3367	207.2926
AR2	LPT	-105.96349	39.21181	.075	-217.7782	5.8512
	SPT	126.40837*	39.21181	.016	14.5937	238.2230
	AR1	-58.44065	39.21181	.671	-170.2553	53.3740
	AR3	34.53707	39.21181	.951	-77.2776	146.3517
	AR4	37.03732	39.21181	.935	-74.7773	148.8520
AR3	LPT	-140.50056*	39.21181	.005	-252.3152	-28.6859
	SPT	91.87131	39.21181	.177	-19.9434	203.6860
	AR1	-92.97772	39.21181	.167	-204.7924	18.8369
	AR2	-34.53707	39.21181	.951	-146.3517	77.2776
	AR4	2.50025	39.21181	1.000	-109.3144	114.3149
AR4	LPT	-143.00081*	39.21181	.004	-254.8155	-31.1862
	SPT	89.37105	39.21181	.203	-22.4436	201.1857
	AR1	-95.47797	39.21181	.145	-207.2926	16.3367
	AR2	-37.03732	39.21181	.935	-148.8520	74.7773
	AR3	-2.50025	39.21181	1.000	-114.3149	109.3144

*. The mean difference is significant at the 0.05 level.

Table D 12

Case 2: Comparison of Sequencing Rules in Scenario 3, $P_E = 0\%$

Dependent Variable: WT15IT15OT
Tukey HSD

(I) Rule	(J) Rule	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
LPT	SPT	236.74068*	54.59845	.000	81.0502	392.4312
	AR1	56.48188	54.59845	.906	-99.2086	212.1724
	AR2	105.47754	54.59845	.383	-50.2130	261.1681
	AR3	136.05326	54.59845	.127	-19.6373	291.7438
	AR4	167.77199*	54.59845	.026	12.0815	323.4625
SPT	LPT	-236.74068*	54.59845	.000	-392.4312	-81.0502
	AR1	-180.25880*	54.59845	.012	-335.9493	-24.5683
	AR2	-131.26313	54.59845	.155	-286.9536	24.4274
	AR3	-100.68742	54.59845	.437	-256.3779	55.0031
	AR4	-68.96869	54.59845	.805	-224.6592	86.7218
AR1	LPT	-56.48188	54.59845	.906	-212.1724	99.2086
	SPT	180.25880*	54.59845	.012	24.5683	335.9493
	AR2	48.99566	54.59845	.947	-106.6948	204.6862
	AR3	79.57138	54.59845	.692	-76.1191	235.2619
	AR4	111.29011	54.59845	.321	-44.4004	266.9806
AR2	LPT	-105.47754	54.59845	.383	-261.1681	50.2130
	SPT	131.26313	54.59845	.155	-24.4274	286.9536
	AR1	-48.99566	54.59845	.947	-204.6862	106.6948
	AR3	30.57571	54.59845	.994	-125.1148	186.2662
	AR4	62.29445	54.59845	.864	-93.3961	217.9850
AR3	LPT	-136.05326	54.59845	.127	-291.7438	19.6373
	SPT	100.68742	54.59845	.437	-55.0031	256.3779
	AR1	-79.57138	54.59845	.692	-235.2619	76.1191
	AR2	-30.57571	54.59845	.994	-186.2662	125.1148
	AR4	31.71873	54.59845	.992	-123.9718	187.4092
AR4	LPT	-167.77199*	54.59845	.026	-323.4625	-12.0815
	SPT	68.96869	54.59845	.805	-86.7218	224.6592
	AR1	-111.29011	54.59845	.321	-266.9806	44.4004
	AR2	-62.29445	54.59845	.864	-217.9850	93.3961
	AR3	-31.71873	54.59845	.992	-187.4092	123.9718

*. The mean difference is significant at the 0.05 level.

Table D 13

Case 2: Comparison of FI and VI for Short Procedures, $P_E = 10\%$

Dependent Variable: WT5IT5OT
Tukey HSD

(I) Rule	(J) Rule	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
FI2	VI2	28.37419	67.96271	.908	-131.0690	187.8173
	VI4	4.94146	67.96271	.997	-154.5017	164.3846
VI2	FI2	-28.37419	67.96271	.908	-187.8173	131.0690
	VI4	-23.43273	67.96271	.937	-182.8759	136.0104
VI4	FI2	-4.94146	67.96271	.997	-164.3846	154.5017
	VI2	23.43273	67.96271	.937	-136.0104	182.8759

Table D 14

Case 2: Comparison of FI and VI for Short Procedures, $P_E = 10\%$

Dependent Variable: WT10IT10OT
Tukey HSD

(I) Rule	(J) Rule	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
FI3	VI2	58.30347	106.70892	.848	-192.0398	308.6467
	VI4	51.94118	106.70892	.878	-198.4021	302.2844
VI2	FI3	-58.30347	106.70892	.848	-308.6467	192.0398
	VI4	-6.36229	106.70892	.998	-256.7055	243.9810
VI4	FI3	-51.94118	106.70892	.878	-302.2844	198.4021
	VI2	6.36229	106.70892	.998	-243.9810	256.7055

Table D 15

Case 2: Comparison of FI and VI for Short Procedures, $P_E = 10\%$

Dependent Variable: WT15IT15OT
Tukey HSD

(I) Rule	(J) Rule	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
FI3	VI3	80.28366	146.55136	.848	-263.5315	424.0988
	VI4	45.95083	146.55136	.947	-297.8643	389.7660
VI3	FI3	-80.28366	146.55136	.848	-424.0988	263.5315
	VI4	-34.33284	146.55136	.970	-378.1480	309.4823
VI4	FI3	-45.95083	146.55136	.947	-389.7660	297.8643
	VI3	34.33284	146.55136	.970	-309.4823	378.1480

Table D 16

Case 2: Comparison of FI and VI for Long Procedures, $P_E = 10\%$

T-Test

Group Statistics

	Rule	N	Mean	Std. Deviation	Std. Error Mean
WT5IT 5OT	FI9	500	463.8495	490.43356	21.93286
	VI 8	500	460.9012	489.16597	21.87617

Independent Samples Test

		Levene's Test for Equality of Variances	
		F	Sig.
WT5IT 5OT	Equal variances assumed	.010	.922
	Equal variances not assumed		

Independent Samples Test

		t-test for Equality of Means			
		t	df	Sig. (2-tailed)	Mean Difference
WT5IT 5OT	Equal variances assumed	.095	998	.924	2.94836
	Equal variances not assumed	.095	997.993	.924	2.94836

Independent Samples Test

		t-test for Equality of Means		
		Std. Error Difference	95% Confidence Interval of the Difference	
			Lower	Upper
WT5IT 5OT	Equal variances assumed	30.97768	-57.84050	63.73723
	Equal variances not assumed	30.97768	-57.84050	63.73723

Table D 17

Case 2: Comparison of FI and VI for Long Procedures, $P_E = 10\%$

T-Test

Group Statistics

	Rule	N	Mean	Std. Deviation	Std. Error Mean
WT10IT 10OT	FI13	500	760.1837	904.59720	40.45482
	VI10	500	756.2788	904.33329	40.44301

Independent Samples Test

		Levene's Test for Equality of Variances	
		F	Sig.
WT10IT 10OT	Equal variances assumed	.001	.976
	Equal variances not assumed		

Independent Samples Test

		t-test for Equality of Means			
		t	df	Sig. (2-tailed)	Mean Difference
WT10IT 10OT	Equal variances assumed	.068	998	.946	3.90489
	Equal variances not assumed	.068	998.000	.946	3.90489

Independent Samples Test

		t-test for Equality of Means		
		Std. Error Difference	95% Confidence Interval of the Difference	
			Lower	Upper
WT10IT 10OT	Equal variances assumed	57.20341	-108.34786	116.15764
	Equal variances not assumed	57.20341	-108.34786	116.15764

Table D 18

Case 2: Comparison of FI and VI for Long Procedures, $P_E = 10\%$

T-Test

Group Statistics

	Rule	N	Mean	Std. Deviation	Std. Error Mean
WT15IT 15OT	FI15	500	1038.6679	1318.04956	58.94497
	VI11	500	1033.5678	1316.53782	58.87736

Independent Samples Test

		Levene's Test for Equality of Variances	
		F	Sig.
WT15IT 15OT	Equal variances assumed	.001	.976
	Equal variances not assumed		

Independent Samples Test

		t-test for Equality of Means			
		t	df	Sig. (2-tailed)	Mean Difference
WT15IT 15OT	Equal variances assumed	.061	998	.951	5.10008
	Equal variances not assumed	.061	997.999	.951	5.10008

Independent Samples Test

		t-test for Equality of Means		
		Std. Error Difference	95% Confidence Interval of the Difference	
			Lower	Upper
WT15IT 15OT	Equal variances assumed	83.31298	-158.38864	168.58880
	Equal variances not assumed	83.31298	-158.38864	168.58880

Table D 19

Case 2: Comparison of Sequencing Rules in Scenario 2, $P_E = 10\%$

Dependent Variable: WT5IT5OT

Tukey HSD

(I) RULE	(J) RULE	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
LPT	SPT	135.97609*	54.18505	.033	8.8559	263.0963
	AR3	37.26309	54.18505	.771	-89.8571	164.3833
SPT	LPT	-135.97609*	54.18505	.033	-263.0963	-8.8559
	AR3	-98.71300	54.18505	.163	-225.8332	28.4072
AR3	LPT	-37.26309	54.18505	.771	-164.3833	89.8571
	SPT	98.71300	54.18505	.163	-28.4072	225.8332

*. The mean difference is significant at the 0.05 level.

Table D 20

Case 2: Comparison of Sequencing Rules in Scenario 2, $P_E = 10\%$

Dependent Variable WT10IT10OT

Tukey HSD

(I) RULE	(J) RULE	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
LPT	SPT	194.05701	91.46676	.086	-20.5275	408.6416
	AR3	52.06492	91.46676	.837	-162.5196	266.6495
SPT	LPT	-194.05701	91.46676	.086	-408.6416	20.5275
	AR3	-141.99208	91.46676	.267	-356.5766	72.5925
AR3	LPT	-52.06492	91.46676	.837	-266.6495	162.5196
	SPT	141.99208	91.46676	.267	-72.5925	356.5766

Table D 21

Case 2: Comparison of Sequencing Rules in Scenario 2, $P_E = 10\%$

Dependent Variable: WT15IT15OT

Tukey HSD

(I) RULE	(J) RULE	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
LPT	SPT	186.52350	129.17494	.319	-116.5259	489.5729
	AR3	24.59550	129.17494	.980	-278.4539	327.6449
SPT	LPT	-186.52350	129.17494	.319	-489.5729	116.5259
	AR3	-161.92800	129.17494	.422	-464.9774	141.1214
AR3	LPT	-24.59550	129.17494	.980	-327.6449	278.4539
	SPT	161.92800	129.17494	.422	-141.1214	464.9774

Table D 22

Case 2: Comparison of Sequencing Rules in Scenario 3, $P_E = 10\%$

Dependent Variable: WT5IT5OT
Tukey HSD

(I) Rule	(J) Rule	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
LPT	SPT	135.27743*	41.68016	.015	16.4241	254.1307
	AR1	23.05733	41.68016	.994	-95.7960	141.9106
	AR2	57.73648	41.68016	.736	-61.1168	176.5898
	AR3	72.38783	41.68016	.507	-46.4655	191.2411
	AR4	94.44383	41.68016	.208	-24.4095	213.2971
SPT	LPT	-135.27743*	41.68016	.015	-254.1307	-16.4241
	AR1	-112.22011	41.68016	.077	-231.0734	6.6332
	AR2	-77.54096	41.68016	.427	-196.3942	41.3123
	AR3	-62.88960	41.68016	.659	-181.7429	55.9637
	AR4	-40.83360	41.68016	.924	-159.6869	78.0197
AR1	LPT	-23.05733	41.68016	.994	-141.9106	95.7960
	SPT	112.22011	41.68016	.077	-6.6332	231.0734
	AR2	34.67915	41.68016	.962	-84.1741	153.5324
	AR3	49.33051	41.68016	.845	-69.5228	168.1838
	AR4	71.38650	41.68016	.523	-47.4668	190.2398
AR2	LPT	-57.73648	41.68016	.736	-176.5898	61.1168
	SPT	77.54096	41.68016	.427	-41.3123	196.3942
	AR1	-34.67915	41.68016	.962	-153.5324	84.1741
	AR3	14.65135	41.68016	.999	-104.2019	133.5046
	AR4	36.70735	41.68016	.951	-82.1459	155.5606
AR3	LPT	-72.38783	41.68016	.507	-191.2411	46.4655
	SPT	62.88960	41.68016	.659	-55.9637	181.7429
	AR1	-49.33051	41.68016	.845	-168.1838	69.5228
	AR2	-14.65135	41.68016	.999	-133.5046	104.2019
	AR4	22.05600	41.68016	.995	-96.7973	140.9093
AR4	LPT	-94.44383	41.68016	.208	-213.2971	24.4095
	SPT	40.83360	41.68016	.924	-78.0197	159.6869
	AR1	-71.38650	41.68016	.523	-190.2398	47.4668
	AR2	-36.70735	41.68016	.951	-155.5606	82.1459
	AR3	-22.05600	41.68016	.995	-140.9093	96.7973

*. The mean difference is significant at the 0.05 level.

Table D 23

Case 2: Comparison of Sequencing Rules in Scenario 3, $P_E = 10\%$

Dependent Variable: WT10IT10OT
Tukey HSD

(I) Rule	(J) Rule	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
LPT	SPT	201.71326	72.82046	.063	-5.9384	409.3649
	AR1	33.97727	72.82046	.997	-173.6743	241.6289
	AR2	87.80267	72.82046	.834	-119.8489	295.4543
	AR3	115.40137	72.82046	.609	-92.2502	323.0530
	AR4	137.31947	72.82046	.411	-70.3321	344.9711
SPT	LPT	-201.71326	72.82046	.063	-409.3649	5.9384
	AR1	-167.73599	72.82046	.193	-375.3876	39.9156
	AR2	-113.91058	72.82046	.622	-321.5622	93.7410
	AR3	-86.31188	72.82046	.844	-293.9635	121.3397
	AR4	-64.39379	72.82046	.950	-272.0454	143.2578
AR1	LPT	-33.97727	72.82046	.997	-241.6289	173.6743
	SPT	167.73599	72.82046	.193	-39.9156	375.3876
	AR2	53.82541	72.82046	.977	-153.8262	261.4770
	AR3	81.42410	72.82046	.874	-126.2275	289.0757
	AR4	103.34220	72.82046	.715	-104.3094	310.9938
AR2	LPT	-87.80267	72.82046	.834	-295.4543	119.8489
	SPT	113.91058	72.82046	.622	-93.7410	321.5622
	AR1	-53.82541	72.82046	.977	-261.4770	153.8262
	AR3	27.59870	72.82046	.999	-180.0529	235.2503
	AR4	49.51680	72.82046	.984	-158.1348	257.1684
AR3	LPT	-115.40137	72.82046	.609	-323.0530	92.2502
	SPT	86.31188	72.82046	.844	-121.3397	293.9635
	AR1	-81.42410	72.82046	.874	-289.0757	126.2275
	AR2	-27.59870	72.82046	.999	-235.2503	180.0529
	AR4	21.91810	72.82046	1.000	-185.7335	229.5697
AR4	LPT	-137.31947	72.82046	.411	-344.9711	70.3321
	SPT	64.39379	72.82046	.950	-143.2578	272.0454
	AR1	-103.34220	72.82046	.715	-310.9938	104.3094
	AR2	-49.51680	72.82046	.984	-257.1684	158.1348
	AR3	-21.91810	72.82046	1.000	-229.5697	185.7335

Table D 24

Case 2: Comparison of Sequencing Rules in Scenario 3, $P_E = 10\%$

Dependent Variable: WT15IT15OT
Tukey HSD

(I) Rule	(J) Rule	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
LPT	SPT	205.84310	104.08991	.355	-90.9751	502.6613
	AR1	47.36245	104.08991	.998	-249.4557	344.1806
	AR2	86.82578	104.08991	.961	-209.9924	383.6440
	AR3	108.55000	104.08991	.903	-188.2682	405.3682
	AR4	166.44843	104.08991	.599	-130.3697	463.2666
SPT	LPT	-205.84310	104.08991	.355	-502.6613	90.9751
	AR1	-158.48065	104.08991	.650	-455.2988	138.3375
	AR2	-119.01731	104.08991	.863	-415.8355	177.8009
	AR3	-97.29310	104.08991	.938	-394.1113	199.5251
	AR4	-39.39466	104.08991	.999	-336.2128	257.4235
AR1	LPT	-47.36245	104.08991	.998	-344.1806	249.4557
	SPT	158.48065	104.08991	.650	-138.3375	455.2988
	AR2	39.46334	104.08991	.999	-257.3548	336.2815
	AR3	61.18755	104.08991	.992	-235.6306	358.0057
	AR4	119.08599	104.08991	.863	-177.7322	415.9042
AR2	LPT	-86.82578	104.08991	.961	-383.6440	209.9924
	SPT	119.01731	104.08991	.863	-177.8009	415.8355
	AR1	-39.46334	104.08991	.999	-336.2815	257.3548
	AR3	21.72422	104.08991	1.000	-275.0940	318.5424
	AR4	79.62265	104.08991	.973	-217.1955	376.4408
AR3	LPT	-108.55000	104.08991	.903	-405.3682	188.2682
	SPT	97.29310	104.08991	.938	-199.5251	394.1113
	AR1	-61.18755	104.08991	.992	-358.0057	235.6306
	AR2	-21.72422	104.08991	1.000	-318.5424	275.0940
	AR4	57.89844	104.08991	.994	-238.9197	354.7166
AR4	LPT	-166.44843	104.08991	.599	-463.2666	130.3697
	SPT	39.39466	104.08991	.999	-257.4235	336.2128
	AR1	-119.08599	104.08991	.863	-415.9042	177.7322
	AR2	-79.62265	104.08991	.973	-376.4408	217.1955
	AR3	-57.89844	104.08991	.994	-354.7166	238.9197

Appendix E Simulation Results of Case 3

Table E 1

Case 3: FI and VI for Moderate Procedures, $P_E = 0\%$

	Fixed Interval Rule					Dome Rule			Increasing Interval Rule		
	FI 1	**FI 3**	**FI 5**	**FI 7**	**FI 9**	**VI 13**	**VI 14**	**VI 15**	**VI 16**	**VI 17**	**VI 18**
Performance Measure	**Average, 95% C.I.**										
Total Waiting Time (min)	80.70 ± 9.79	108.11 ± 11.1	143.34 ± 12.31	187.17 ± 13.29	237.91 ± 13.93	170.5 ± 13.01	219.21 ± 13.8	274.7 ± 14.16	152.69 ± 12.81	199.86 ± 13.72	254.84 ± 14.14
Total Idle Time (min)	39.04 ± 2.97	23.34 ± 2.23	11.93 ± 1.48	4.99 ± 0.82	1.35 ± 0.33	6.76 ± 1.05	2.02 ± 0.48	0.19 ± 0.09	8.95 ± 1.35	2.67 ± 0.63	0.33 ± 0.17
Overtime (min)	22.17 ± 4.14	19.15 ± 3.97	17.58 ± 3.87	16.86 ± 3.81	16.49 ± 3.77	16.95 ± 3.82	16.51 ± 3.77	16.31 ± 3.76	17.04 ± 3.82	16.51 ± 3.77	16.31 ± 3.76
Utilization	0.91 ± 0.01	0.94 ± 0.01	0.97 ± 0	0.99 ± 0	1.00 ± 0	0.98 ± 0	0.99 ± 0	1.00 ± 0	0.98 ± 0	0.99 ± 0	1.00 ± 0
WTITOT	141.91 ± 11.8	150.6 ± 13.22	172.85 ± 14.61	209.01 ± 15.76	255.75 ± 16.52	194.21 ± 15.4	237.75 ± 16.34	291.21 ± 16.79	178.68 ± 15.08	219.04 ± 16.22	271.48 ± 16.75
WT5IT5OT	386.74 ± 26.78	320.57 ± 26.94	290.89 ± 27.73	296.38 ± 28.73	327.12 ± 29.52	289.02 ± 28.32	311.87 ± 29.28	357.23 ± 29.8	282.62 ± 27.88	295.77 ± 29.08	338.05 ± 29.74
WT10IT10OT	692.77 ± 48.47	533.03 ± 46.81	438.43 ± 46.45	405.59 ± 46.9	416.34 ± 47.51	407.53 ± 46.54	404.53 ± 47.27	439.76 ± 47.74	412.54 ± 46.2	391.67 ± 47.04	421.26 ± 47.67
WT15IT15OT	998.8 ± 70.65	745.49 ± 67.22	585.98 ± 65.7	514.8 ± 65.56	505.55 ± 65.98	526.05 ± 65.29	497.19 ± 65.73	522.28 ± 66.14	542.47 ± 65.08	487.58 ± 65.49	504.47 ± 66.05
WT20IT20OT	1304.84 ± 92.98	957.95 ± 87.79	733.53 ± 85.12	624.01 ± 84.39	594.77 ± 84.6	644.57 ± 84.2	589.85 ± 84.35	604.81 ± 84.7	672.39 ± 84.14	583.48 ± 84.12	587.68 ± 84.6

Table E 2

Case 3: FI and VI for Moderate Procedures, $P_E = 10\%$

	Fixed Interval Rule					Dome Rule			Increasing Interval Rule		
	FI 1	**FI 3**	**FI 5**	**FI 7**	**FI 9**	**VI 13**	**VI 14**	**VI 15**	**VI 16**	**VI 17**	**VI 18**
Performance Measure	**Average, 95% C.I.**										
Total Waiting Time (min)	123.47 ± 14.06	152.55 ± 15.38	181.07 ± 15.62	218.95 ± 15.81	264.65 ± 15.72	204.98 ± 15.77	249.19 ± 16.15	297.96 ± 15.68	188.93 ± 15.78	231.14 ± 16.12	280.1 ± 15.64
Total Idle Time (min)	33.5 ± 2.93	20.34 ± 2.15	10.65 ± 1.41	4.52 ± .78	1.25 ± .32	6.06 ± 0.99	1.79 ± 0.45	0.18 ± 0.08	7.68 ± 1.25	2.3 ± 0.6	0.31 ± 0.16
Overtime (min)	53.65 ± 7.73	49.75 ± 7.58	47.35 ± 7.47	46.13 ± 7.40	45.48 ± 7.37	46.26 ± 7.41	45.52 ± 7.37	45.19 ± 7.36	46.39 ± 7.41	45.55 ± 7.37	45.19 ± 7.36
Utilization	1.0 ± 0	1.0 ± 0	1.0 ± 0	1.0 ± 0	1.0 ± 0	1.0 ± 0	1.0 ± 0	1.0 ± 0	1.0 ± 0	1.0 ± 0	1.0 ± 0
WTITOT	210.62 ± 18.54	222.65 ± 20.04	239.08 ± 20.38	269.6 ± 20.51	311.38 ± 20.38	257.3 ± 20.53	296.5 ± 20.87	343.33 ± 20.37	243 ± 20.57	278.99 ± 20.85	325.61 ± 20.35
WT5IT5OT	559.21 ± 45.29	503.04 ± 46.39	471.09 ± 46.63	472.21 ± 46.66	498.29 ± 46.54	466.57 ± 46.65	485.74 ± 47	524.82 ± 46.6	459.28 ± 46.63	470.39 ± 46.96	507.64 ± 46.6
WT10IT10OT	994.95 ± 81.93	853.53 ± 82.42	761.1 ± 82.41	725.46 ± 82.39	731.93 ± 82.33	728.17 ± 82.24	722.29 ± 82.72	751.67 ± 82.47	729.64 ± 82.1	709.64 ± 82.64	735.18 ± 82.45
WT15IT15OT	1430.69 ± 119.10	1204.02 ± 118.98	1051.12 ± 118.73	978.71 ± 118.68	965.57 ± 118.68	989.76 ± 118.37	958.83 ± 118.99	978.52 ± 118.88	999.99 ± 118.1	948.89 ± 118.87	962.71 ± 118.84
WT20IT20OT	1866.42 ± 156.41	1554.51 ± 155.71	1341.13 ± 155.20	1231.96 ± 155.12	1199.2 ± 155.19	1251.35 ± 154.65	1195.38 ± 155.44	1205.38 ± 155.46	1270.34 ± 154.25	1188.13 ± 155.26	1190.25 ± 155.4

Appendix F ANOVA Results of Case 3

Table F 1

Case 3: Comparison of FI and VI for Moderate Procedures, $P_E = 0\%$

Dependent Variable: WT5IT5OT
Tukey HSD

(I) Rule	(J) Rule	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
VI5	VI13	1.86872	20.08421	.995	-45.2496	48.9871
	VI16	8.26926	20.08421	.911	-38.8491	55.3876
VI13	VI5	-1.86872	20.08421	.995	-48.9871	45.2496
	VI16	6.40054	20.08421	.946	-40.7178	53.5189
VI16	VI5	-8.26926	20.08421	.911	-55.3876	38.8491
	VI13	-6.40054	20.08421	.946	-53.5189	40.7178

Table F 2

Case 3: Comparison of FI and VI for Moderate Procedures, $P_E = 0\%$

Dependent Variable: WT10IT10OT
Tukey HSD

(I) Rule	(J) Rule	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
VI7	VI14	1.05383	33.78924	.999	-78.2170	80.3247
	VI17	13.91616	33.78924	.911	-65.3547	93.1870
VI14	VI7	-1.05383	33.78924	.999	-80.3247	78.2170
	VI17	12.86232	33.78924	.923	-66.4085	92.1332
VI17	VI7	-13.91616	33.78924	.911	-93.1870	65.3547
	VI14	-12.86232	33.78924	.923	-92.1332	66.4085

Table F 3

Case 3: Comparison of FI and VI for Moderate Procedures, $P_E = 0\%$

Dependent Variable: WT15IT15OT
Tukey HSD

(I) Rule	(J) Rule	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
VI9	VI14	8.36149	47.18745	.983	-102.3421	119.0651
	VI17	17.97940	47.18745	.923	-92.7242	128.6830
VI14	VI9	-8.36149	47.18745	.983	-119.0651	102.3421
	VI17	9.61791	47.18745	.977	-101.0857	120.3215
VI17	VI9	-17.97940	47.18745	.923	-128.6830	92.7242
	VI14	-9.61791	47.18745	.977	-120.3215	101.0857

Table F 4

Case 3: Comparison of Sequencing Rules in Combination 1, Scenario 3, $P_E = 0\%$

Dependent Variable: WT5IT5OT
Tukey HSD

(I) Rule	(J) Rule	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
LPT	SPT	146.74848*	25.44412	.000	74.1932	219.3038
	AR1	13.55106	25.44412	.995	-59.0043	86.1064
	AR2	24.16055	25.44412	.933	-48.3948	96.7159
	AR3	54.42480	25.44412	.267	-18.1305	126.9801
	AR4	57.54758	25.44412	.210	-15.0077	130.1029
SPT	LPT	-146.74848*	25.44412	.000	-219.3038	-74.1932
	AR1	-133.19742*	25.44412	.000	-205.7527	-60.6421
	AR2	-122.58793*	25.44412	.000	-195.1433	-50.0326
	AR3	-92.32368*	25.44412	.004	-164.8790	-19.7684
	AR4	-89.20090*	25.44412	.006	-161.7562	-16.6456
AR1	LPT	-13.55106	25.44412	.995	-86.1064	59.0043
	SPT	133.19742*	25.44412	.000	60.6421	205.7527
	AR2	10.60949	25.44412	.998	-61.9458	83.1648
	AR3	40.87373	25.44412	.594	-31.6816	113.4291
	AR4	43.99651	25.44412	.512	-28.5588	116.5518
AR2	LPT	-24.16055	25.44412	.933	-96.7159	48.3948
	SPT	122.58793*	25.44412	.000	50.0326	195.1433
	AR1	-10.60949	25.44412	.998	-83.1648	61.9458
	AR3	30.26424	25.44412	.842	-42.2911	102.8196
	AR4	33.38703	25.44412	.778	-39.1683	105.9423
AR3	LPT	-54.42480	25.44412	.267	-126.9801	18.1305
	SPT	92.32368*	25.44412	.004	19.7684	164.8790
	AR1	-40.87373	25.44412	.594	-113.4291	31.6816
	AR2	-30.26424	25.44412	.842	-102.8196	42.2911
	AR4	3.12278	25.44412	1.000	-69.4325	75.6781
AR4	LPT	-57.54758	25.44412	.210	-130.1029	15.0077
	SPT	89.20090*	25.44412	.006	16.6456	161.7562
	AR1	-43.99651	25.44412	.512	-116.5518	28.5588
	AR2	-33.38703	25.44412	.778	-105.9423	39.1683
	AR3	-3.12278	25.44412	1.000	-75.6781	69.4325

*. The mean difference is significant at the 0.05 level.

Table F 5

Case 3: Comparison of Sequencing Rules in Combination 1, Scenario 3, $P_E = 0\%$

Dependent Variable: WT10IT10OT
Tukey HSD

(I) Rule	(J) Rule	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
LPT	SPT	232.44526*	41.41027	.000	114.3616	350.5290
	AR1	21.18638	41.41027	.996	-96.8973	139.2701
	AR2	45.02796	41.41027	.887	-73.0557	163.1117
	AR3	100.32326	41.41027	.149	-17.7604	218.4070
	AR4	101.96802	41.41027	.136	-16.1157	220.0517
SPT	LPT	-232.44526*	41.41027	.000	-350.5290	-114.3616
	AR1	-211.25888*	41.41027	.000	-329.3426	-93.1752
	AR2	-187.41729*	41.41027	.000	-305.5010	-69.3336
	AR3	-132.12200*	41.41027	.018	-250.2057	-14.0383
	AR4	-130.47723*	41.41027	.020	-248.5609	-12.3935
AR1	LPT	-21.18638	41.41027	.996	-139.2701	96.8973
	SPT	211.25888*	41.41027	.000	93.1752	329.3426
	AR2	23.84158	41.41027	.993	-94.2421	141.9253
	AR3	79.13688	41.41027	.395	-38.9468	197.2206
	AR4	80.78164	41.41027	.371	-37.3021	198.8653
AR2	LPT	-45.02796	41.41027	.887	-163.1117	73.0557
	SPT	187.41729*	41.41027	.000	69.3336	305.5010
	AR1	-23.84158	41.41027	.993	-141.9253	94.2421
	AR3	55.29530	41.41027	.765	-62.7884	173.3790
	AR4	56.94006	41.41027	.742	-61.1436	175.0238
AR3	LPT	-100.32326	41.41027	.149	-218.4070	17.7604
	SPT	132.12200*	41.41027	.018	14.0383	250.2057
	AR1	-79.13688	41.41027	.395	-197.2206	38.9468
	AR2	-55.29530	41.41027	.765	-173.3790	62.7884
	AR4	1.64477	41.41027	1.000	-116.4389	119.7285
AR4	LPT	-101.96802	41.41027	.136	-220.0517	16.1157
	SPT	130.47723*	41.41027	.020	12.3935	248.5609
	AR1	-80.78164	41.41027	.371	-198.8653	37.3021
	AR2	-56.94006	41.41027	.742	-175.0238	61.1436
	AR3	-1.64477	41.41027	1.000	-119.7285	116.4389

*. The mean difference is significant at the 0.05 level.

Table F 6

Case 3: Comparison of Sequencing Rules in Combination 1, Scenario 3, $P_E = 0\%$

Dependent Variable: WT15IT15OT
Tukey HSD

(I) Rule	(J) Rule	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
LPT	SPT	248.84468*	56.79085	.000	86.9024	410.7870
	AR1	28.23896	56.79085	.996	-133.7033	190.1813
	AR2	41.26906	56.79085	.979	-120.6732	203.2113
	AR3	98.81970	56.79085	.505	-63.1226	260.7620
	AR4	115.59044	56.79085	.322	-46.3518	277.5327
SPT	LPT	-248.84468*	56.79085	.000	-410.7870	-86.9024
	AR1	-220.60572*	56.79085	.001	-382.5480	-58.6634
	AR2	-207.57563*	56.79085	.004	-369.5179	-45.6333
	AR3	-150.02499	56.79085	.088	-311.9673	11.9173
	AR4	-133.25424	56.79085	.176	-295.1965	28.6880
AR1	LPT	-28.23896	56.79085	.996	-190.1813	133.7033
	SPT	220.60572*	56.79085	.001	58.6634	382.5480
	AR2	13.03009	56.79085	1.000	-148.9122	174.9724
	AR3	70.58073	56.79085	.816	-91.3616	232.5230
	AR4	87.35148	56.79085	.640	-74.5908	249.2938
AR2	LPT	-41.26906	56.79085	.979	-203.2113	120.6732
	SPT	207.57563*	56.79085	.004	45.6333	369.5179
	AR1	-13.03009	56.79085	1.000	-174.9724	148.9122
	AR3	57.55064	56.79085	.914	-104.3916	219.4929
	AR4	74.32139	56.79085	.780	-87.6209	236.2637
AR3	LPT	-98.81970	56.79085	.505	-260.7620	63.1226
	SPT	150.02499	56.79085	.088	-11.9173	311.9673
	AR1	-70.58073	56.79085	.816	-232.5230	91.3616
	AR2	-57.55064	56.79085	.914	-219.4929	104.3916
	AR4	16.77075	56.79085	1.000	-145.1715	178.7130
AR4	LPT	-115.59044	56.79085	.322	-277.5327	46.3518
	SPT	133.25424	56.79085	.176	-28.6880	295.1965
	AR1	-87.35148	56.79085	.640	-249.2938	74.5908
	AR2	-74.32139	56.79085	.780	-236.2637	87.6209
	AR3	-16.77075	56.79085	1.000	-178.7130	145.1715

*. The mean difference is significant at the 0.05 level.

Table F 7

Case 3: Comparison of Sequencing Rules in Combination 2, Scenario 3, $P_E = 0\%$

Dependent Variable: WT5IT5OT
Tukey HSD

(I) Rule	(J) Rule	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
LPT	SPT	84.44369*	16.95031	.000	36.1089	132.7784
	AR1	36.54894	16.95031	.259	-11.7858	84.8837
	AR2	45.83352	16.95031	.075	-2.5012	94.1683
	AR3	60.91670*	16.95031	.004	12.5819	109.2515
	AR4	21.14602	16.95031	.813	-27.1887	69.4808
SPT	LPT	-84.44369*	16.95031	.000	-132.7784	-36.1089
	AR1	-47.89475	16.95031	.054	-96.2295	.4400
	AR2	-38.61017	16.95031	.203	-86.9449	9.7246
	AR3	-23.52699	16.95031	.734	-71.8617	24.8078
	AR4	-63.29767*	16.95031	.003	-111.6324	-14.9629
AR1	LPT	-36.54894	16.95031	.259	-84.8837	11.7858
	SPT	47.89475	16.95031	.054	-.4400	96.2295
	AR2	9.28459	16.95031	.994	-39.0502	57.6193
	AR3	24.36776	16.95031	.704	-23.9670	72.7025
	AR4	-15.40291	16.95031	.944	-63.7377	32.9318
AR2	LPT	-45.83352	16.95031	.075	-94.1683	2.5012
	SPT	38.61017	16.95031	.203	-9.7246	86.9449
	AR1	-9.28459	16.95031	.994	-57.6193	39.0502
	AR3	15.08317	16.95031	.949	-33.2516	63.4179
	AR4	-24.68750	16.95031	.692	-73.0223	23.6473
AR3	LPT	-60.91670*	16.95031	.004	-109.2515	-12.5819
	SPT	23.52699	16.95031	.734	-24.8078	71.8617
	AR1	-24.36776	16.95031	.704	-72.7025	23.9670
	AR2	-15.08317	16.95031	.949	-63.4179	33.2516
	AR4	-39.77067	16.95031	.176	-88.1054	8.5641
AR4	LPT	-21.14602	16.95031	.813	-69.4808	27.1887
	SPT	63.29767*	16.95031	.003	14.9629	111.6324
	AR1	15.40291	16.95031	.944	-32.9318	63.7377
	AR2	24.68750	16.95031	.692	-23.6473	73.0223
	AR3	39.77067	16.95031	.176	-8.5641	88.1054

*. The mean difference is significant at the 0.05 level.

Table F 8

Case 3: Comparison of Sequencing Rules in Combination 2, Scenario 3, $P_E = 0\%$

Dependent Variable: WT10IT10OT
Tukey HSD

(I) Rule	(J) Rule	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
LPT	SPT	118.01646*	28.79744	.001	35.8990	200.1340
	AR1	45.21633	28.79744	.618	-36.9012	127.3338
	AR2	63.79290	28.79744	.231	-18.3246	145.9104
	AR3	89.20949*	28.79744	.024	7.0920	171.3270
	AR4	25.52320	28.79744	.950	-56.5943	107.6407
SPT	LPT	-118.01646*	28.79744	.001	-200.1340	-35.8990
	AR1	-72.80013	28.79744	.116	-154.9176	9.3174
	AR2	-54.22356	28.79744	.413	-136.3411	27.8939
	AR3	-28.80697	28.79744	.918	-110.9245	53.3105
	AR4	-92.49326*	28.79744	.017	-174.6108	-10.3758
AR1	LPT	-45.21633	28.79744	.618	-127.3338	36.9012
	SPT	72.80013	28.79744	.116	-9.3174	154.9176
	AR2	18.57657	28.79744	.988	-63.5409	100.6941
	AR3	43.99316	28.79744	.646	-38.1243	126.1107
	AR4	-19.69313	28.79744	.984	-101.8106	62.4244
AR2	LPT	-63.79290	28.79744	.231	-145.9104	18.3246
	SPT	54.22356	28.79744	.413	-27.8939	136.3411
	AR1	-18.57657	28.79744	.988	-100.6941	63.5409
	AR3	25.41659	28.79744	.951	-56.7009	107.5341
	AR4	-38.26970	28.79744	.769	-120.3872	43.8478
AR3	LPT	-89.20949*	28.79744	.024	-171.3270	-7.0920
	SPT	28.80697	28.79744	.918	-53.3105	110.9245
	AR1	-43.99316	28.79744	.646	-126.1107	38.1243
	AR2	-25.41659	28.79744	.951	-107.5341	56.7009
	AR4	-63.68629	28.79744	.233	-145.8038	18.4312
AR4	LPT	-25.52320	28.79744	.950	-107.6407	56.5943
	SPT	92.49326*	28.79744	.017	10.3758	174.6108
	AR1	19.69313	28.79744	.984	-62.4244	101.8106
	AR2	38.26970	28.79744	.769	-43.8478	120.3872
	AR3	63.68629	28.79744	.233	-18.4312	145.8038

*. The mean difference is significant at the 0.05 level.

Table F 9

Case 3: Comparison of Sequencing Rules in Combination 2, Scenario 3, $P_E = 0\%$

Dependent Variable: WT15IT15OT
Tukey HSD

(I) Rule	(J) Rule	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
LPT	SPT	128.93687*	40.65319	.019	13.0120	244.8617
	AR1	62.48008	40.65319	.640	-53.4448	178.4049
	AR2	66.98801	40.65319	.567	-48.9368	182.9129
	AR3	101.34534	40.65319	.126	-14.5795	217.2702
	AR4	35.21733	40.65319	.954	-80.7075	151.1422
SPT	LPT	-128.93687*	40.65319	.019	-244.8617	-13.0120
	AR1	-66.45679	40.65319	.575	-182.3816	49.4681
	AR2	-61.94886	40.65319	.649	-177.8737	53.9760
	AR3	-27.59152	40.65319	.984	-143.5164	88.3333
	AR4	-93.71954	40.65319	.192	-209.6444	22.2053
AR1	LPT	-62.48008	40.65319	.640	-178.4049	53.4448
	SPT	66.45679	40.65319	.575	-49.4681	182.3816
	AR2	4.50793	40.65319	1.000	-111.4169	120.4328
	AR3	38.86526	40.65319	.932	-77.0596	154.7901
	AR4	-27.26275	40.65319	.985	-143.1876	88.6621
AR2	LPT	-66.98801	40.65319	.567	-182.9129	48.9368
	SPT	61.94886	40.65319	.649	-53.9760	177.8737
	AR1	-4.50793	40.65319	1.000	-120.4328	111.4169
	AR3	34.35733	40.65319	.959	-81.5675	150.2822
	AR4	-31.77068	40.65319	.971	-147.6955	84.1542
AR3	LPT	-101.34534	40.65319	.126	-217.2702	14.5795
	SPT	27.59152	40.65319	.984	-88.3333	143.5164
	AR1	-38.86526	40.65319	.932	-154.7901	77.0596
	AR2	-34.35733	40.65319	.959	-150.2822	81.5675
	AR4	-66.12801	40.65319	.581	-182.0529	49.7968
AR4	LPT	-35.21733	40.65319	.954	-151.1422	80.7075
	SPT	93.71954	40.65319	.192	-22.2053	209.6444
	AR1	27.26275	40.65319	.985	-88.6621	143.1876
	AR2	31.77068	40.65319	.971	-84.1542	147.6955
	AR3	66.12801	40.65319	.581	-49.7968	182.0529

*. The mean difference is significant at the 0.05 level.

Table F 10

Case 3: Comparison of FI and VI for Moderate Procedures, $P_E = 10\%$

Dependent Variable: WT5IT5OT
Tukey HSD

(I) Rule	(J) Rule	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
FI5	VI13	4.51421	33.48116	.990	-74.0339	83.0623
	VI16	11.80376	33.48116	.934	-66.7443	90.3519
VI13	FI5	-4.51421	33.48116	.990	-83.0623	74.0339
	VI16	7.28955	33.48116	.974	-71.2585	85.8376
VI16	FI5	-11.80376	33.48116	.934	-90.3519	66.7443
	VI13	-7.28955	33.48116	.974	-85.8376	71.2585

Table F 11

Case 3: Comparison of FI and VI for Moderate Procedures, $P_E = 10\%$

Dependent Variable: WT10IT10OT
Tukey HSD

(I) Rule	(J) Rule	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
FI7	VI14	3.17063	59.28334	.998	-135.9104	142.2516
	VI17	15.81995	59.28334	.962	-123.2610	154.9009
VI14	FI7	-3.17063	59.28334	.998	-142.2516	135.9104
	VI17	12.64933	59.28334	.975	-126.4317	151.7303
VI17	FI7	-15.81995	59.28334	.962	-154.9009	123.2610
	VI14	-12.64933	59.28334	.975	-151.7303	126.4317

Table F 12

Case 3: Comparison of FI and VI for Moderate Procedures, $P_E = 10\%$

Dependent Variable: WT15IT15OT
Tukey HSD

(I) Rule	(J) Rule	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
VI9	VI14	6.73108	85.31670	.997	-193.4252	206.8873
	VI17	16.67973	85.31670	.979	-183.4765	216.8360
VI14	VI9	-6.73108	85.31670	.997	-206.8873	193.4252
	VI17	9.94865	85.31670	.993	-190.2076	210.1049
VI17	VI9	-16.67973	85.31670	.979	-216.8360	183.4765
	VI14	-9.94865	85.31670	.993	-210.1049	190.2076

Table F 13

Case 3: Comparison of Sequencing Rules in Combination 1, Scenario 3, $P_E = 10\%$

Dependent Variable: WT5IT5OT
Tukey HSD

(I) Rule	(J) Rule	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
LPT	SPT	124.11521	47.04409	.089	-10.0337	258.2641
	AR1	4.18427	47.04409	1.000	-129.9646	138.3331
	AR2	6.15875	47.04409	1.000	-127.9901	140.3076
	AR3	40.11571	47.04409	.957	-94.0331	174.2646
	AR4	46.49711	47.04409	.922	-87.6517	180.6460
SPT	LPT	-124.11521	47.04409	.089	-258.2641	10.0337
	AR1	-119.93094	47.04409	.110	-254.0798	14.2179
	AR2	-117.95646	47.04409	.122	-252.1053	16.1924
	AR3	-83.99950	47.04409	.475	-218.1484	50.1494
	AR4	-77.61809	47.04409	.565	-211.7669	56.5308
AR1	LPT	-4.18427	47.04409	1.000	-138.3331	129.9646
	SPT	119.93094	47.04409	.110	-14.2179	254.0798
	AR2	1.97448	47.04409	1.000	-132.1744	136.1233
	AR3	35.93144	47.04409	.973	-98.2174	170.0803
	AR4	42.31285	47.04409	.947	-91.8360	176.4617
AR2	LPT	-6.15875	47.04409	1.000	-140.3076	127.9901
	SPT	117.95646	47.04409	.122	-16.1924	252.1053
	AR1	-1.97448	47.04409	1.000	-136.1233	132.1744
	AR3	33.95696	47.04409	.979	-100.1919	168.1058
	AR4	40.33837	47.04409	.956	-93.8105	174.4872
AR3	LPT	-40.11571	47.04409	.957	-174.2646	94.0331
	SPT	83.99950	47.04409	.475	-50.1494	218.1484
	AR1	-35.93144	47.04409	.973	-170.0803	98.2174
	AR2	-33.95696	47.04409	.979	-168.1058	100.1919
	AR4	6.38141	47.04409	1.000	-127.7674	140.5303
AR4	LPT	-46.49711	47.04409	.922	-180.6460	87.6517
	SPT	77.61809	47.04409	.565	-56.5308	211.7669
	AR1	-42.31285	47.04409	.947	-176.4617	91.8360
	AR2	-40.33837	47.04409	.956	-174.4872	93.8105
	AR3	-6.38141	47.04409	1.000	-140.5303	127.7674

Table F 14

Case 3: Comparison of Sequencing Rules in Combination 1, Scenario 3, $P_E = 10\%$

Dependent Variable: WT10IT10OT
Tukey HSD

(I) Rule	(J) Rule	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
LPT	SPT	192.23698	79.44940	.150	-34.3174	418.7914
	AR1	14.86552	79.44940	1.000	-211.6889	241.4199
	AR2	24.42695	79.44940	1.000	-202.1274	250.9813
	AR3	69.19656	79.44940	.953	-157.3578	295.7509
	AR4	77.67997	79.44940	.925	-148.8744	304.2343
SPT	LPT	-192.23698	79.44940	.150	-418.7914	34.3174
	AR1	-177.37146	79.44940	.223	-403.9258	49.1829
	AR2	-167.81003	79.44940	.281	-394.3644	58.7443
	AR3	-123.04042	79.44940	.633	-349.5948	103.5140
	AR4	-114.55702	79.44940	.701	-341.1114	111.9974
AR1	LPT	-14.86552	79.44940	1.000	-241.4199	211.6889
	SPT	177.37146	79.44940	.223	-49.1829	403.9258
	AR2	9.56143	79.44940	1.000	-216.9929	236.1158
	AR3	54.33104	79.44940	.984	-172.2233	280.8854
	AR4	62.81445	79.44940	.969	-163.7399	289.3688
AR2	LPT	-24.42695	79.44940	1.000	-250.9813	202.1274
	SPT	167.81003	79.44940	.281	-58.7443	394.3644
	AR1	-9.56143	79.44940	1.000	-236.1158	216.9929
	AR3	44.76961	79.44940	.993	-181.7848	271.3240
	AR4	53.25302	79.44940	.985	-173.3014	279.8074
AR3	LPT	-69.19656	79.44940	.953	-295.7509	157.3578
	SPT	123.04042	79.44940	.633	-103.5140	349.5948
	AR1	-54.33104	79.44940	.984	-280.8854	172.2233
	AR2	-44.76961	79.44940	.993	-271.3240	181.7848
	AR4	8.48340	79.44940	1.000	-218.0710	235.0378
AR4	LPT	-77.67997	79.44940	.925	-304.2343	148.8744
	SPT	114.55702	79.44940	.701	-111.9974	341.1114
	AR1	-62.81445	79.44940	.969	-289.3688	163.7399
	AR2	-53.25302	79.44940	.985	-279.8074	173.3014
	AR3	-8.48340	79.44940	1.000	-235.0378	218.0710

Table F 15

Case 3: Comparison of Sequencing Rules in Combination 1, Scenario 3, $P_E = 10\%$

Dependent Variable: WT15IT15OT
Tukey HSD

(I) Rule	(J) Rule	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
LPT	SPT	199.55466	112.14359	.479	-120.2290	519.3384
	AR1	20.93447	112.14359	1.000	-298.8492	340.7182
	AR2	14.69077	112.14359	1.000	-305.0929	334.4745
	AR3	60.08025	112.14359	.995	-259.7034	379.8640
	AR4	104.77823	112.14359	.938	-215.0055	424.5619
SPT	LPT	-199.55466	112.14359	.479	-519.3384	120.2290
	AR1	-178.62019	112.14359	.603	-498.4039	141.1635
	AR2	-184.86389	112.14359	.566	-504.6476	134.9198
	AR3	-139.47440	112.14359	.815	-459.2581	180.3093
	AR4	-94.77643	112.14359	.959	-414.5601	225.0073
AR1	LPT	-20.93447	112.14359	1.000	-340.7182	298.8492
	SPT	178.62019	112.14359	.603	-141.1635	498.4039
	AR2	-6.24370	112.14359	1.000	-326.0274	313.5400
	AR3	39.14578	112.14359	.999	-280.6379	358.9295
	AR4	83.84376	112.14359	.976	-235.9399	403.6275
AR2	LPT	-14.69077	112.14359	1.000	-334.4745	305.0929
	SPT	184.86389	112.14359	.566	-134.9198	504.6476
	AR1	6.24370	112.14359	1.000	-313.5400	326.0274
	AR3	45.38948	112.14359	.999	-274.3942	365.1732
	AR4	90.08746	112.14359	.967	-229.6962	409.8712
AR3	LPT	-60.08025	112.14359	.995	-379.8640	259.7034
	SPT	139.47440	112.14359	.815	-180.3093	459.2581
	AR1	-39.14578	112.14359	.999	-358.9295	280.6379
	AR2	-45.38948	112.14359	.999	-365.1732	274.3942
	AR4	44.69798	112.14359	.999	-275.0857	364.4817
AR4	LPT	-104.77823	112.14359	.938	-424.5619	215.0055
	SPT	94.77643	112.14359	.959	-225.0073	414.5601
	AR1	-83.84376	112.14359	.976	-403.6275	235.9399
	AR2	-90.08746	112.14359	.967	-409.8712	229.6962
	AR3	-44.69798	112.14359	.999	-364.4817	275.0857

Table F 16

Case 3: Comparison of Sequencing Rules in Combination 2, Scenario 3, $P_E = 10\%$

Dependent Variable: WT5IT5OT
Tukey HSD

(I) Rule	(J) Rule	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
LPT	SPT	79.76498	30.32651	.090	-6.7128	166.2427
	AR1	38.81707	30.32651	.796	-47.6607	125.2948
	AR2	42.79027	30.32651	.720	-43.6875	129.2680
	AR3	58.57645	30.32651	.383	-27.9013	145.0542
	AR4	23.17834	30.32651	.973	-63.2994	109.6561
SPT	LPT	-79.76498	30.32651	.090	-166.2427	6.7128
	AR1	-40.94791	30.32651	.757	-127.4256	45.5298
	AR2	-36.97471	30.32651	.828	-123.4524	49.5030
	AR3	-21.18853	30.32651	.982	-107.6663	65.2892
	AR4	-56.58665	30.32651	.424	-143.0644	29.8911
AR1	LPT	-38.81707	30.32651	.796	-125.2948	47.6607
	SPT	40.94791	30.32651	.757	-45.5298	127.4256
	AR2	3.97320	30.32651	1.000	-82.5045	90.4509
	AR3	19.75938	30.32651	.987	-66.7184	106.2371
	AR4	-15.63873	30.32651	.996	-102.1165	70.8390
AR2	LPT	-42.79027	30.32651	.720	-129.2680	43.6875
	SPT	36.97471	30.32651	.828	-49.5030	123.4524
	AR1	-3.97320	30.32651	1.000	-90.4509	82.5045
	AR3	15.78618	30.32651	.995	-70.6916	102.2639
	AR4	-19.61193	30.32651	.987	-106.0897	66.8658
AR3	LPT	-58.57645	30.32651	.383	-145.0542	27.9013
	SPT	21.18853	30.32651	.982	-65.2892	107.6663
	AR1	-19.75938	30.32651	.987	-106.2371	66.7184
	AR2	-15.78618	30.32651	.995	-102.2639	70.6916
	AR4	-35.39811	30.32651	.852	-121.8758	51.0796
AR4	LPT	-23.17834	30.32651	.973	-109.6561	63.2994
	SPT	56.58665	30.32651	.424	-29.8911	143.0644
	AR1	15.63873	30.32651	.996	-70.8390	102.1165
	AR2	19.61193	30.32651	.987	-66.8658	106.0897
	AR3	35.39811	30.32651	.852	-51.0796	121.8758

Table F 17

Case 3: Comparison of Sequencing Rules in Combination 2, Scenario 3, $P_E = 10\%$

Dependent Variable: WT10IT10OT
Tukey HSD

(I) Rule	(J) Rule	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
LPT	SPT	107.32818	53.75534	.344	-45.9582	260.6145
	AR1	46.84288	53.75534	.953	-106.4435	200.1292
	AR2	54.70958	53.75534	.912	-98.5768	207.9959
	AR3	79.11409	53.75534	.682	-74.1722	232.4004
	AR4	28.07559	53.75534	.995	-125.2107	181.3619
SPT	LPT	-107.32818	53.75534	.344	-260.6145	45.9582
	AR1	-60.48531	53.75534	.871	-213.7716	92.8010
	AR2	-52.61860	53.75534	.925	-205.9049	100.6677
	AR3	-28.21410	53.75534	.995	-181.5004	125.0722
	AR4	-79.25260	53.75534	.681	-232.5389	74.0337
AR1	LPT	-46.84288	53.75534	.953	-200.1292	106.4435
	SPT	60.48531	53.75534	.871	-92.8010	213.7716
	AR2	7.86671	53.75534	1.000	-145.4196	161.1530
	AR3	32.27121	53.75534	.991	-121.0151	185.5575
	AR4	-18.76729	53.75534	.999	-172.0536	134.5190
AR2	LPT	-54.70958	53.75534	.912	-207.9959	98.5768
	SPT	52.61860	53.75534	.925	-100.6677	205.9049
	AR1	-7.86671	53.75534	1.000	-161.1530	145.4196
	AR3	24.40450	53.75534	.998	-128.8818	177.6908
	AR4	-26.63400	53.75534	.996	-179.9203	126.6523
AR3	LPT	-79.11409	53.75534	.682	-232.4004	74.1722
	SPT	28.21410	53.75534	.995	-125.0722	181.5004
	AR1	-32.27121	53.75534	.991	-185.5575	121.0151
	AR2	-24.40450	53.75534	.998	-177.6908	128.8818
	AR4	-51.03850	53.75534	.933	-204.3248	102.2478
AR4	LPT	-28.07559	53.75534	.995	-181.3619	125.2107
	SPT	79.25260	53.75534	.681	-74.0337	232.5389
	AR1	18.76729	53.75534	.999	-134.5190	172.0536
	AR2	26.63400	53.75534	.996	-126.6523	179.9203
	AR3	51.03850	53.75534	.933	-102.2478	204.3248

Table F 18

Case 3: Comparison of Sequencing Rules in Combination 2, Scenario 3, $P_E = 10\%$

Dependent Variable: WT15IT15OT
Tukey HSD

(I) Rule	(J) Rule	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
LPT	SPT	114.00242	77.62497	.684	-107.3495	335.3544
	AR1	63.66330	77.62497	.964	-157.6886	285.0152
	AR2	54.55901	77.62497	.982	-166.7929	275.9109
	AR3	86.64861	77.62497	.875	-134.7033	308.0005
	AR4	37.05329	77.62497	.997	-184.2986	258.4052
SPT	LPT	-114.00242	77.62497	.684	-335.3544	107.3495
	AR1	-50.33912	77.62497	.987	-271.6911	171.0128
	AR2	-59.44341	77.62497	.973	-280.7953	161.9085
	AR3	-27.35381	77.62497	.999	-248.7057	193.9981
	AR4	-76.94913	77.62497	.921	-298.3011	144.4028
AR1	LPT	-63.66330	77.62497	.964	-285.0152	157.6886
	SPT	50.33912	77.62497	.987	-171.0128	271.6911
	AR2	-9.10429	77.62497	1.000	-230.4562	212.2476
	AR3	22.98531	77.62497	1.000	-198.3666	244.3372
	AR4	-26.61001	77.62497	.999	-247.9619	194.7419
AR2	LPT	-54.55901	77.62497	.982	-275.9109	166.7929
	SPT	59.44341	77.62497	.973	-161.9085	280.7953
	AR1	9.10429	77.62497	1.000	-212.2476	230.4562
	AR3	32.08960	77.62497	.998	-189.2623	253.4415
	AR4	-17.50572	77.62497	1.000	-238.8577	203.8462
AR3	LPT	-86.64861	77.62497	.875	-308.0005	134.7033
	SPT	27.35381	77.62497	.999	-193.9981	248.7057
	AR1	-22.98531	77.62497	1.000	-244.3372	198.3666
	AR2	-32.08960	77.62497	.998	-253.4415	189.2623
	AR4	-49.59532	77.62497	.988	-270.9473	171.7566
AR4	LPT	-37.05329	77.62497	.997	-258.4052	184.2986
	SPT	76.94913	77.62497	.921	-144.4028	298.3011
	AR1	26.61001	77.62497	.999	-194.7419	247.9619
	AR2	17.50572	77.62497	1.000	-203.8462	238.8577
	AR3	49.59532	77.62497	.988	-171.7566	270.9473